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FEASIBILITY STUDY FOR A TACTICAL LORAN-D ANTENNA

I. E. Johnson
T. S. Cory

Collins Radio Company

TECHNICAL REPORT NO. RADC-TR-67-162
April 1967

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Rome Air Development Center
Research and Technology Division
Air Force Systems Command
Griffiss Air Force Base, New York

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FOREWORD

This Final Technical Report encompasses all work performed under Contract AF33(615)-3339 from 29 November 1965 to September 1966. This manuscript was released for publication by the authors on January 31, 1967.

The program was accomplished by the Antenna Division of Collins Radio Company, Richardson, Texas under the technical direction of Mr. R. S. Jones/EMAEI, Rome Air Development Center.

The authors of this program were Mr. I. E. Johnson, Project Engineer and Mr. T. S. Cory. Those who contributed significant assistance in the preparation of this report were Messrs. R. H. Sliger, W. G. Jones, H. R. Wilson, and Dr. W. L. Weeks.

Release of subject report to the general public is prohibited by the Strategic Trade Control Program, Mutual Defense Assistance Control List (revised 6 January 1965), published by the Department of State.

The efforts described were carried out under Project 681A. This technical report has been reviewed and is approved.

Approved: RICHARD S. JONES
Project Engineer

Approved: THOMAS S. BOND, JR.
Colonel, USAF
Chief, Surveillance &
Control Division

FOR THE COMMANDER:

FOR THE COMMANDER:
IRVING J. GABELMAN
Chief, Advanced Studies Group

ABSTRACT

The feasibility of a lightweight, tactical, Loran D antenna system is examined in this study. The existing Sperry system is used as a basis for comparison to achieve either an improved electrical performance utilizing the present mechanical characteristics, or retaining the present systems electrical parameters and achieving superior tactical and mechanical properties.

The program was accomplished by evaluating efficiency - bandwidth products for a variety of electrical configurations while a concurrent mechanical study was being made involving various structural designs, materials, and methods. Finally, the findings of the electrical and mechanical studies were combined, resulting in four recommended possible approaches.

The antenna recommended as a result of this study is a basic umbrella configuration. The support structure recommended is an optimized version of the snap-out tower presently employed. Optimization of the tower involved increased guy diameters to provide linear tower displacement, increasing the leg wall thickness from 0.095 to 0.125 inch, and decreasing the horizontal tower member spacing to 30 inches from 36 inches.

The specified erection time of 10 men - 8 hours for antenna installation was judged feasible due to past performance of the existing system. The system weight using one of the recommended configurations is estimated to be between 5500 to 6500 pounds.

Four basic systems recommended as a result of the study are as follows:

1. INCREASED η X BW OVER STANDARD ANTENNA

a. A tower height of 300 feet with 12 umbrella radiators result in a η X BW of 133. This system would weigh approximately 6,500 pounds and have a volume of approximately 550 cubic feet.

b. A 300-foot tower with an umbrella consisting of 12 radiators with a skirt wire provide a ηXBW of 170. The estimated weight of this system is 6,500 pounds and the volume is estimated to be 550 cubic feet

2. η X BW = 100 OPTIONS

a. A tower 275 feet in height supporting a 12 radiator umbrella resulted in a η X BW of 100. The estimated weight is 6,100 pounds and the estimated volume is 540 cubic feet.

b. A 250-foot tower supporting an umbrella consisting of 12 radiators with a skirt wire provides a η X BW of 100. Estimated weight and volume of this system is 5,800 pounds and 530 cubic feet respectively.

EVALUATION

1. The objective of this study is to determine the feasibility of a lightweight, tactical Loran-D Antenna System whose electrical performance and general mechanical characteristics are superior over the present antenna system.

2. The approach taken by the contractor was to conduct an electrical performance study by building a variety of antenna configurations on a scale model basis and evaluate their electrical characteristics. Concurrent with the electrical study a mechanical study was made whereby various available tower designs, anchors, conductor and materials, state-of-the-art erection techniques, and other properties are evaluated with tactical requirements in mind. Finally the results of the electrical and mechanical studies are combined and the basis for a development specification is given for one or more antenna systems optimized with respect to the tactical requirements.

3. The antenna system recommended is an optimized version of the snap-out tower presently employed.

4. Although no exotic antenna designs were uncovered, the study does provide design curves useful in evaluating various L.F. antenna configurations applicable to Loran-D. The study also provides detail information relative to various tower structures.

Richard S Jones

Richard S. Jones
Project Engineer

TABLE OF CONTENTS

TABLE OF CONTENTS (Cont)

LIST OF ILLUSTRATIONS

LIST OF ILLUSTRATIONS (Cont)

LIST OF ILLUSTRATIONS (Cont)

LIST OF TABLES

LIST OF ABBREVIATIONS

η	efficiency
BW	bandwidth
KHz	kilohertz
$h_{1, 2}$	tower height
f	frequency
L	leg, (tower)
D	diagonal (tower)
H	horizontal (tower)
h	height between tower horizontal members
psi	pounds per square inch
F.S.	factor of safety
d	distance between tower legs, in.
Q	reciprocal of percent bandwidth
Δf	frequency increment between 3 db selectivity points of antenna under matched conditions of frequency f as measured at antenna input.
R_a	input resistance
Z_o	input characteristic impedance
η_L	loss efficiency
PTAM	perfect actual matched antenna
PMAM	perfect short matched monopole
R_r	input resistance
β_ℓ	electrical length
C	input capacitance

W_E	mean stored electric energy
W_H	mean stored magnetic energy
λ..............	wavelength
K_a..............	radius of hemisphere in radians
K	characteristic impedance of bicone
P_n..............	Legendre polynomial of order n
$\hat{H}_n (\beta R_o)$	spherical Bessel function of order n
$H_n' (\beta R_o)$........	derivative with respect to n
Z_{in}	input impedance at apex of bicone
ℓ_{hm}.............	load reflection coefficient
Z_{oB}.............	biconical line characteristic impedance
θ_{eB}	equivalent cone angle at biconical section
R_a..............	input resistance
X_a..............	input reactance
θ_B..............	base cone angle
X_L	Load reactance
h_T..............	Total tower height, ft.
h_m	unmasked tower height, ft.
X_m	equivalent series inductive reactance
ℓ_μ..............	umbrella wire length
r..............	tower radius
D_m	mast diameter

kh	mast height, radians
kr	radius, radians
H_o, H_1	Hankel functions
J_n (Kr), N_n (kr)	Bessel functions
f_R	series resonant frequency
W_R	received power
Vm	measured voltage
V_{oc}	open circuit voltage
E_{inc} (θ_o, ϕ_o)	incident field strength impinging in desired direction
A (θ_o, ϕ_o)	antenna aperature in desired direction
A_{PMM}	aperature of perfect short matched monopole
Z_{in}	impedance read at bridge
Z_o	50 ohm line impedance
Z_r	impedance rotated through transmission line
tan $\beta \ell$	tangent of electrical angle of rotation
X_{sc}	short circuit reactance reading
Z_a	antenna impedance
R_a	antenna resistive component
X_a	antenna reactive component
X_b	base capacitance
f_o	operating frequency at band center
V_m	voltage at antenna terminals
ρ	wire radius in inches

h_w . . . . wire height in inches

p_r . . . . sphere radius in centimeters

R_1 . . . . shunt dielectric loss resistance

X_1 . . . . shunt capacitance of insulations

X_{ei} . . . . shunt terminal zone capacitance external to the dielectric

R_{pa} . . . . shunt or parallel equivalent input resistance

σ . . . . insulator conductivity

ϵ_r . . . . relative dielectric constant

ϵ_o . . . . air dielectric constant

tan δ . . . . loss tangent

C_i . . . . insulator capacitance

I . . . . moment of inertia, in^4

E . . . . modulus of elasticity, psi

t_{W_L} . . . . tower leg wall thickness, in.

D_L . . . . tower leg diameter, in.

AG . . . . shear stiffness

t_{W_D} . . . . diagonal wall thickness, in.

D_D . . . . diagonal diameter, in.

T_{W_H} . . . . horizontal wall thickness, in.

D_H . . . . horizontal diameter, in.

K . . . . spring rate lbs/in

AE . . . . stiffness of guy wires

S . . . . distance from tower base to guy anchor

ℓ	height from ground to tower guy point
W	wind loading in lbs/ft
C_D	drag coefficient
V	wind velocity in mph
t_{ice}	ice thickness on member
α	angle of incidence of member to wind direction
$\Delta\ell_i$	length of i^{th} section of tower
f_i	load forces on i^{th} section of tower
F_j	restraining forces on j^{th} guy
m_o, f_o	top loads on tower
F_B	base shear on tower
F'_B L_B	base mount on tower
MTBF	mean time between failure
L/r	slenderness ratio of member
L/D	lift to drag ratio

SECTION I

INTRODUCTION

The object of this study is to determine the feasibility of a light-weight, tactical Loran D antenna system. This objective is accomplished by effecting improvement over the existing Sperry 300-foot, 9-wire umbrella design. To achieve this improvement, the goal of the study is either to improve the electrical performance with a design having the same general mechanical characteristics as the Sperry antenna; or for nominal performance, comparable to the Sperry antenna, to provide a design with superior mechanical and tactical properties.

The program approach is as follows:

a. An electrical performance study is made by building a variety of antenna configurations on a scale model basis and evaluating their electrical characteristics.

b. Concurrent with the electrical study, a mechanical study is made whereby various available tower designs, anchors, conductor and guy materials, state-of-the-art erection techniques, and other properties are evaluated with tactical requirements in mind.

c. Finally, the results of the electrical and mechanical studies are combined and the basis for a development specification is given for one or more antenna systems optimized with respect to the tactical requirements.

The measure for evaluating electrical performance is efficiency-bandwidth product (abbreviated η XBW). The criterion for this evaluation is maximum η XBW for minimum land area and tower height (300-foot hemisphere maximum volume allowed). Of primary importance to the mechanical study is a computer program which permits an iterative evaluation of structural members for a given configuration; the result is an optimally stressed mechanical design. The best electrical designs and the most suitable mechanical components are used with this program to yield a design that is truly optimum for the given tactical constraints.

The main body of the report begins with a technical approach section (Section III) where the characteristics of the electrical and mechanical configurations are determined analytically. Electrically, the possible configurations fall into three classes:

a. Umbrella or top-loaded vertical types.

b. Monocone-monocage types.

c. Transmission line types.

These models are analyzed and conclusions are drawn on purely theoretical grounds. Mechanically, the considerations influencing the structural design are presented together with the analytical basis for the stress analysis computer program.

This section also contains the empirical technique for the electrical measurements; also a discussion of full scale limitations and the mathematical basis for their evaluation.

The second section of the main body (Section IV) presents the data gathered from the electrical study, the computer analysis of various supporting structures, and back-up data on structural components. This data is then compared with the considerations of Section III and qualitative analysis is given with respect to the tactical impact of the results. The result of this analysis is the basis for the developmental specification for optimum system(s).

The ground rules, trade offs and the results of this study are summarized in Section II.

SECTION II

SUMMARY

1. GENERAL

The comparative analysis of antenna configurations, support structures, and associated equipment, has resulted in four basic configurations which satisfies the requirements of a lightweight, tactical, Loran D antenna system. The selected techniques and components are within the present state-of-the-art, and are capable of satisfying the mission requirements of the system.

As a basis for the study, the system specifications shown in Appendix 1 together with the additional ground rules in the following section were used. Also contained in the following section are the system trade-offs implemented in obtaining the following results and recommendations.

2. GROUND RULES AND TRADE-OFFS

a. WEIGHTING FACTORS

To augment the imposed antenna system requirements of Appendix 1, additional weighting factors are required in order to more specifically establish system design goals. These weighting factors are:

(1) The standard for comparison is the Sperry system currently employed. The summarized characteristics of this antenna are:

Efficiency Bandwidth Product: (ηXBW) = 116

No. of umbrella wires:	9
Umbrella angle:	45 degrees
Length of umbrella wires:	305 feet
Tower height:	303 feet
No. of ground radials:	9 @ 300 feet
Weight of system:	6000 pounds
Erection time:	10 men/8 hours

(2) One KHz bandwidth or greater is required. The system ηXBW will be 100 or greater (assumed 10% efficiency).

(3) For a given ηXBW, electrical configurations are evaluated in terms of land area required for a tower height of 300 ft.

(4) A sufficient number of ground radials of sufficient length to insure "impedance stability" with climatic changes are required.

(5) Wind and ice specifications (see appendix 1) are considered firm on all types of support structures. Effects of reduced environmental conditions on the guys are considered if loads become a critical factor.

(6) A factor of safety of 2 to 1 will be in effect for all structural members.

b. TRADE-OFFS

Trade-offs used in the comparative analyses of the antenna system are:

(1) Increasing land area to improve ηXBW.

(2) Increase number of radiator wires to improve ηXBW.

(3) Addition of skirt wire to umbrella to improve ηXBW.

(4) Increase in weight and volume from additional equipment to facilitate assembly and erection.

(5) If required, increase system cost to provide improved tactical capability.

(6) Emphasis on reusable components as opposed to expendable items.

(7) Emphasis on design, simplicity, and ruggedness resulting in increased system reliability as opposed to a more complex design with above average electrical performance.

3. RESULTS

The antenna recommended as a result of this study is a properly designed umbrella configuration. The support structure resulting from the study is an optimized configuration of the snap-out tower presently used.

Factors influencing the umbrella design are:

a. Fixing other parameters, the increase in efficiency-bandwidth product (ηXBW) for an increase in tower height from h_1 to h_2 is $\left(\frac{h_2}{h_1}\right)^3$ times (ηXBW).

b. Fixing other parameters, the increase in ηXBW for increase in frequency f_1 to new frequency f_2 is $(f_2/f_1)^4$ (ηXBW).

c. The ηXBW increases when the number of umbrella wires is increased. For instance, an umbrella with an optimum $1/b_T$ and angle Φ_T of the order of 45 - 50 degrees, the following increases in ηXBW may be achieved:

Umbrella Wires	% Increase
6 - 9	24%
9 - 12	16%
12 - 24	20%
9 - 24	38%

d. The addition of a skirt wire of the same diameter as the radiator wires results in approximately a 30 percent increase in ηXBW.

e. An increase in allowable land area will give an increase in ηXBW. For the conditions of paragraph c preceding and using 12 radiators, an increase in land area of 33 percent resulting from a 10 percent increase in tower height, results in an ηXBW increase of 33 percent for an initial ηXBW of approximately 100.

f. For umbrella angles which are reasonable for Loran D (40 - 50 degrees) the umbrella wire length is approximately equal to the tower height for maximum ηXBW.

g. No significant reduction in ground loss resistance is achieved when using an excess of 40 ground radials.

h. For power handling, the most critical component is the base insulator. The insulator should be 24 to 30 inches high with a minimum diameter. For normal dielectrics (porcelain or fiberglass resin) the dielectric loss is not critical if the insulator diameter is less than 10 inches.

The type of support structure recommended as a result of the study is an optimized version of the Up-Right Tower Company currently employed. Table 1 illustrates a comparison of the standard and the optimized versions of this tower. As shown in table 1, a small margin of safety exists in critical areas, notably the tower legs and guy ropes, in the present design.

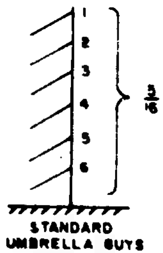
Improvements resulting in optimization of the tower are:

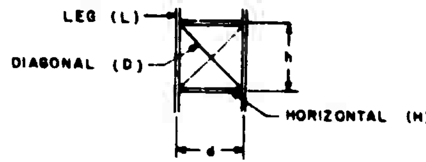
(1) Increase guy sizes with height to provide linear deflection of the tower, and resulting minimum of bending in tower.

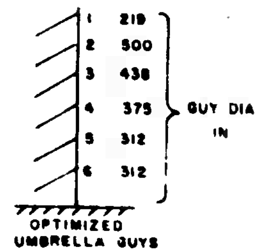
(2) Increase leg wall thickness from 0.095 to 0.125 inches.

(3) Change spacing of horizontal members from 36 to 30 inches, thereby decreasing the l/r and increasing the allowable stress level.

TABLE 1. RESULTS OF OPTIMIZATION OF STANDARD ANTENNA SUPPORT STRUCTURE







	MEMBER SIZE, INCHES			MAXIMUM STRESS, PSI			ALLOWABLE STRESS PSI SAFETY FACTOR = 2			MAX. TOWER DEFLECTION	MAX GUY LOAD	ALLOW. GUY LOAD F.S. = 2	TOWER WT/FT	PARAMETERS, INCHES	
TOWER	L	H	D	L	H	D	L	H	D	FT	LBS	LBS.	LBS./FT	h	d
STANDARD UMBRELLA	2 X 035	2 X 038	3/16	31,235	6,012	36,414	19,000	17,500	40,800	9 378	8,165	5,000	9 3	36	36
OPTIMIZED STANDARD UMBRELLA	2 X 125	2 X .058	3/16	25,991	6,986	39,000	26,000	17,500	40,800	4 443	9,672	9,000	10.0	30	36

4. RECOMMENDATIONS

a. Increased BW system (over Standard Antenna)

(1) $\eta \times BW = 133$

Tower Height:	300 feet
No. of Radiators:	12 (No Skirt Wire)
Radius of Antenna:	345 feet
Radiator - Tower Included Angle:	49°
Radiator Material:	Aluminum Braid Jacketed Glastran
Guy Diameters (Glastran):	
Guy No. 1 (Radiators):	3/16 inch
Guy No. 2:	1/2 inch
Guy No. 3:	7/16 inch
Guy No. 4:	3/8 inch
Guy No. 5:	5/16 inch
Guy No. 6:	5/16 inch
Anchors, Class 6 & 7 Soils:	
Radiators:	10-inch screw anchors, 12 each
Guys:	13-inch screw anchors, 15 each
Anchors, Class 3, 4 & 5 Soils:	
Radiators:	6 by 22-inch Deadman, 12 each
Guys:	6 by 22-inch Deadman, 15 each
Estimated Volume:	550 cubic feet
Estimated Weight:	6500 pounds
Installation Time:	10 men, 8 hours
Ground Screen:	40 radials, 350-feet long # 13 Aluminum Wire

(2) η x BW = 170

Tower Height:	300 feet
No. of Radiators:	12 (with skirt)
Radius of Antenna:	345 feet
Radiator - Tower included Angle:	49°
Radiator Material:	Aluminum Braid Jacketed Glastran
Guy Diameters (Glastran):	
Guy No. 1 (Radiators):	3/16 inch
Guy No. 2	1/2 inch
Guy No. 3	7/16 inch
Guy No. 4	3/8 inch
Guy No. 5	5/16 inch
Guy No. 6	5/16 inch
Anchors, Class 6 & 7 Soils:	
Radiators:	10-inch screw anchor, 12 each
Guys:	13-inch screw anchor, 12 each
Anchors, Class 3, 4, 5 Soils:	
Radiators:	6 by 22 inch Deadman, 12 each
Guys:	6 by 22-inch Deadman, 12 each
Estimated Volume:	550 cubic feet.
Estimated Weight:	6500 pounds
Installation Time:	10 men, 8 hours
Ground Screen:	40 radials, 350-feet long, #13 Aluminum Wire

b. η x BW = 100 Options

(1) η x BW = 100 (no skirt)

Tower Height:	275 feet

No. of Radiators:	12
Radius of Antenna:	300 feet
Radiator - Tower Included Angle:	47-1/2°
Radiator Material:	Aluminum Braid Jacketed Glastran
Guy Diameters (Glastran)	
Guy No. 1 (Radiators):	3/16 inch
Guy No. 2:	1/2 inch
Guy No. 3:	7/16 inch
Guy No. 4:	3/8 inch
Guy No. 5:	5/16 inch
Anchors, Class 6 & 7 Soils:	
Radiators:	10-inch screw anchor, 12 each
Guys:	13-inch screw anchor, 12 each
Anchors, Class 3, 4 & 5 Soils:	
Radiators:	6 by 22-inch Deadman, 12 each
Guys:	6 by 22-inch Deadman, 12 each
Estimated Volume:	540 cubic feet
Estimated Weight:	6100 pounds
Installation Time:	10 men, 8 hours
Ground Screen:	40 wires, 300 feet long #13 Aluminum wire

(2) $\eta \times BW = 100$ (with skirt)

Tower Height:	250 feet
No. of Radials:	12, with skirt
Radius of Antenna:	300 feet
Radiator - Tower Included Angle:	50°

Radiator Material:	**Aluminum Braid Jacketed Glastran**
Guy Diameters (Glastran):	
Guy No. 1 (Radiators):	**3/16 inch**
Guy No. 2:	**1/2 inch**
Guy No. 3:	**7/16 inch**
Guy No. 4:	**3/8 inch**
Guy No. 5:	**5/16 inch**
Anchors, Class 6 & 7 Soils:	
Radiators:	**10-inch screw anchor, 12 each**
Guys:	**13-inch screw anchor, 12 each**
Anchors, Class 3, 4, & 5 Soils:	
Radiators:	**6 by 22-inch Deadman, 12 each**
Guys:	**6 by 22-inch Deadman, 12 each**
Estimated Volume:	**530 cubic feet**
Estimated Weight:	**5800 pounds**
Installation Time:	**10 men, 8 hours**
Ground Screen:	**40 radials, 300-feet long #13 Aluminum Wire**

SECTION III

TECHNICAL APPROACH

1. GENERAL

The possible electrical configurations fall into three basic classifications: top-loaded vertical types or umbrella, monocone-monocage types, and transmission line types, which are defined in this section. Also, the efficiency-bandwidth product (η x BW) is quantitatively defined.

The test facility, with which the antenna scale models were tested and data obtained, is described.

Full-scale electrical considerations described include power limitations, corona minimization, insulator design, ground screen design, and lighting system design.

Mechanical considerations influencing the structural design are presented, as is the analytical background for the stress analysis computer program used on applicable types of support structures.

2. ELECTRICAL CONSIDERATIONS

a. MATHEMATICAL MODELS

In the process of determining optimum antenna configurations, it is necessary to define efficiency-bandwidth product and to place theoretical and practical upper limits on its value for the volume containing the antenna. The size of this volume is defined in terms of electrical size. For the Loran-D requirements, it is approximately 0.03 wavelengths in radius. At a frequency of 100 KHz, this volume has a lineal radius of 300 feet. The antenna configurations studied are generally constrained to fit within this volume.

The percent bandwidth may be defined as the reciprocal of Q and is given by

$$\% \text{ BW} = \frac{1}{Q} = \frac{\Delta f}{f} \times 100$$

where

f is the frequency

Δf is the frequency increment between the 3 db selectivity points of the antenna under matched conditions at frequency f as measured at the antenna input.

The bandwidth in cycles is then

$$BW = \Delta f = \frac{f}{Q} = \frac{f\,R_a}{Z_o}$$

where

$$Q = \frac{Z_o}{R_a}$$

and

R_a is the input resistance

Z_o is the input characteristic impedance.

Correspondingly, efficiency may be defined as

$$\eta = \frac{A_{\text{actual antenna when matched}}}{A_{\text{perfect short monopole when matched}}}$$

where A is the aperture

then,

$$\eta = \eta_L \frac{A_{\text{perfect actual matched antenna}}}{A_{\text{perfect short matched monopole}}}$$

where η_L = loss efficiency

$$= \eta_L \frac{A_{PTAM}}{A_{PMAM}}$$

therefore,

$$\eta \times BW = \eta_L \frac{A_{PTAM}}{A_{PMAM}} \frac{f\,R_a}{Z_o}$$

For electrically small antenna, assuming $A_{PTAM} = A_{PMAM}$ in the direction of interest

$$\eta \times BW = \eta_L \frac{f\,R_a}{Z_o}.$$

Now

$$\eta_L = \frac{R_r}{R_a}$$

where R_r is the component of the input impedance representing radiation.

Then,

$$\eta\,\text{XBW} = \frac{f\,R_r}{Z_o}\,.$$

If R_r is the same as the input resistance for the case of no loss, then η XBW can be calculated for some antennas and η XBW is the same as the bandwidth of the perfect antenna. This means that there is a one for one tradeoff or efficiency for bandwidth. Efficiency, as used here, is also the gain for the surface wave of the test antenna undermatched conditions relative to a perfect short monopole under matched conditions.

For electrically small antennas*

$$Z_o \approx \frac{Z_{oa}}{\beta \ell}$$

where Z_{oa} is the average characteristic impedance

$\beta \ell$ is the electrical length

and, as for the monopole, if the input reactance can be expressed as

$$-jX_a = -j\,Z_{oa}\,\text{Cot}\,\beta \ell$$

where for small angles

$$\text{Cot}\,\beta \ell \approx \frac{1}{\beta \ell}$$

then

$$X_a \approx \frac{Z_{oa}}{\beta \ell} = Z_o = \frac{1}{2\pi f C}$$

where C is the input capacitance.

Thus η XBW may be expressed as

$$\eta\,\text{XBW} = \frac{f\,R_r}{X_a}\,.$$

A more exact definition of Q for a circuit is based on

$$Q = 2\pi\,\frac{\text{energy stored/cycle}}{\text{energy dissipated/cycle}}$$ [1]

* for which an average characteristic impedance may be defined.

$$= 2\pi f \frac{\frac{1}{4} ii^* \frac{\partial X_a}{\partial \omega}}{\text{energy dissipated/sec}}$$

where i is the current and

$$\frac{\partial X_a}{\partial \omega} = \frac{4 (W_H + W_E)}{ii^*}$$

where W_E, W_H are the mean stored electric and magnetic energies.

$$\text{Energy dissipated/sec} = \frac{1}{2} ii^* R$$

such that

$$\text{The unloaded } Q = \frac{\omega}{2R} \frac{\partial X_a}{\partial \omega}$$

for the loaded Q of the circuit where X_T is the total circuit reactance

$$Q = \frac{f_o \left.\frac{d X_a}{d f}\right|_{f_o} + X_a}{2 R}$$

Considering electrically small antennas of the monopole type where the frequency dependence of the reactance is approximately 1/f

$$= f_o \left.\frac{d X_a}{d f}\right|_{f_o} \approx X_a$$

which validates the previous definition of Q.

For two electrically small antennas which differ only in scale factor, the input resistance is given by

$$R_r = K \left(\frac{h}{\lambda}\right)^2$$

where

K is a constant

h is the height

λ is the wavelength.

$$\eta \, XBW = K_1 f^4 (h^3)$$

where K_1 is a constant.

The prime motivation for this study from the Collins point of view is based on the work of Collin & Rothchild[2], Schellkunoff[3], Weeks[4], and others indicating that if the lowest order spherical mode could be established in the volume, the efficiency bandwidth product could be as high as 690 at 100 KHz. For example, a 300-foot hemispherical antenna fed with a slice-generator at the base could excite this mode.

For a spherical antenna, the input impedance at this mode is given by

$$Z = -j\, 80\pi \left[\frac{1}{k_a} - \frac{(J_{1/2}(k_a) - j N_{1/2}(k_a))}{(J_{3/2}(k_a) - j N_{3/2}(k_a))} \right]$$

$$\approx 80\pi \left[\frac{(k_a)^2}{1 + (k_a)^2} \right] - j\, 80\pi \left[\frac{1}{k_a \left[1 + (k_a)^2 \right]} \right]$$

for small k_a where k_a is radius of hemisphere in radians. Using

$$\eta\, XBW = \frac{f R_r}{X_a}$$

$$\eta XBW = (k_a)^3 f = 690.$$

The excitation of the single spherical modes requires a minimum of stored energy.

Practical antenna configuration such as the bicone requires multiple modes to match the boundary conditions between the spherical cap and the biconical line section, thus reducing the maximum achievable η XBW.

(1) Biconical Model.

There are few configurations which are amenable to near-exact analysis due to the inability to fit the conducting surfaces of many antennas to any coordinate system for which wave functions are known. The biconical antenna is one of these few. It most nearly fits the mathematical approach of Collin and Rothchild. It consists of a portion of a spherical antenna fed with a biconical transmission line. The geometry is shown in Figure 1. In the limiting case where $\theta \rightarrow 90$ degrees, the antenna approaches the spherical model discussed previously. Unfortunately, for this case the impedance of the biconical line feeding the sphere becomes so low in value that the input resistance is greatly reduced.

To evaluate the η XBW of monocones, the terminating admittances, Y_{T_1}, pertaining to the bicone were calculated. The method used is that of Tai[5]. Examination of Tai's result shows that the zero order approximation is sufficiently accurate for small cones ($\beta R_0 < .5$) when the angles are in the range of 40-80 degrees. The terminating admittance, for this case, is given by

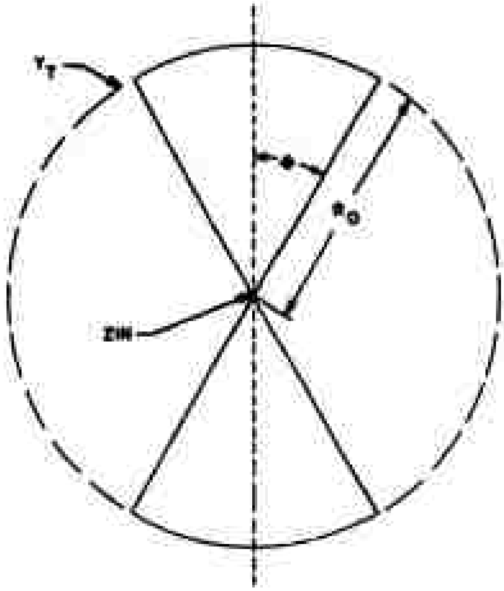


Figure 1. Geometry of the Biconical Antenna

$$Y_T = -j\,\frac{120}{K^2} \sum_{n=1,2,\ldots} \frac{(2n+1)}{n(n+1)}\, P_n^{\,2}\, (\cos\theta)\, \frac{\hat{H}_n\,(\beta R_o)}{\hat{H}'_n\,(\beta R_o)}$$

where

$K = 120 \ln\left(\cot\frac{\theta}{2}\right)$, the characteristic impedance of the bicone.

P_n = is the Legendre polynominal of order n.

$\hat{H}_n\,(\beta R_o)$ is the spherical Bessel function of order n.

$\hat{H}'_n\,(\beta R_o)$ is the derivative with respect to R_o.

The input impedance at the apex of the bicone, $Z_{in} = R+jX$, is calculated by means of the standard transformation equation

$$Z_{in} = K\left[\frac{\cos\beta R_o + j\,K\,Y_T \sin\beta R_o}{K\,Y_T \cos\beta R_o + j \sin\beta R_o}\right]$$

The monocone impedances over perfect ground are then half those of the bicone, however, the η XBW is the same. η XBW was calculated by the formula

$$\eta\,XBW = \frac{f\,R}{X}.$$

The input impedances and bandwidth in Hertz of bicones of 150, 200, 250,300, 350 feet in radius at 100 KH_z, for cone angles ranging from 35-35 degrees are shown in figures 2 through 5 and tables II through VI.

The most interesting result of the above theoretical calculations is that the η XBW increases with decreasing cone angle within the limits of the calculations made. It is obvious that for very small cone angles, the η XBW must decrease and become that of a thin monopole. For the particular case of radius equal to 250 feet, the η XBW based on thin bicone impedance data[6] was plotted and the two sets at data were joined. The results are shown as figure 6. Note that the resistance has a

TABLE II. TERMINATING ADMITTANCE AND INPUT IMPEDANCE @ 100 KHz FOR 150 FOOT RADIUS BICONES VS. CONE ANGLE

θ	150'			
	Y_T Real	$Y_T\ I_m$	Z_{in} Real	$Z_{in}\ I_m$
35	5.34 by 10^{-7}	6.21 by 10^{-4}	3.12 by 10^{-1}	-7.55 by 10^{2}
45	6.28 by 10^{-7}	7.99 by 10^{-4}	2.36 by 10^{-1}	-5.81 by 10^{2}
55	8.19 by 10^{-7}	9.98 by 10^{-4}	1.67 by 10^{-1}	-4.46 by 10^{2}
65	9.31 by 10^{-7}	1.24 by 10^{-3}	1.03 by 10^{-1}	-3.30 by 10^{2}
75	1.01 by 10^{-6}	1.36 by 10^{-3}	4.86 by 10^{-2}	-2.17 by 10^{2}
85	1.06 by 10^{-6}	2.17 by 10^{-3}	8.29 by 10^{-3}	-8.81 by 10^{1}

TABLE III. TERMINATING ADMITTANCE AND INPUT IMPEDANCE @ 100 KHz FOR 200 FOOT RADIUS BICONES VS. CONE ANGLE

θ	200'			
	Y_T Real	$Y_T\ I_m$	Z_{in} Real	$Z_{in}\ I_m$
35	1.70 by 10^{-6}	8.83 by 10^{-4}	5.38 by 10^{-1}	-5.60 by 10^{2}
45	2.17 by 10^{-6}	1.07 by 10^{-3}	4.23 by 10^{-1}	-4.31 by 10^{2}
55	2.61 by 10^{-6}	1.34 by 10^{-3}	2.98 by 10^{-1}	-3.31 by 10^{2}
65	2.97 by 10^{-6}	1.66 by 10^{-3}	1.88 by 10^{-1}	-2.45 by 10^{2}
75	3.22 by 10^{-6}	2.10 by 10^{-3}	8.70 by 10^{-2}	-1.62 by 10^{2}
85	3.36 by 10^{-6}	2.91 by 10^{-3}	1.49 by 10^{-2}	-6.57 by 10^{1}

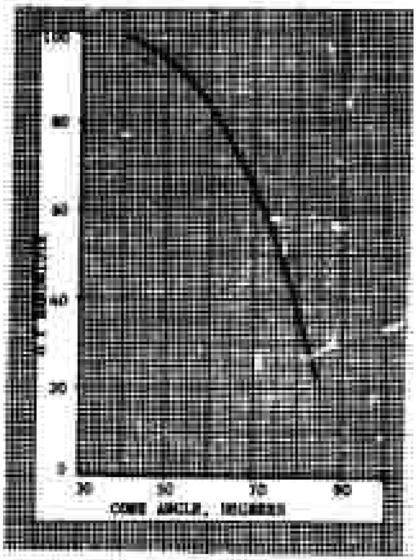


Figure 2. Bandwidth of Monocone Antenna, Radius 200 Feet, at 100 KHz. Cone Angle as Parameter

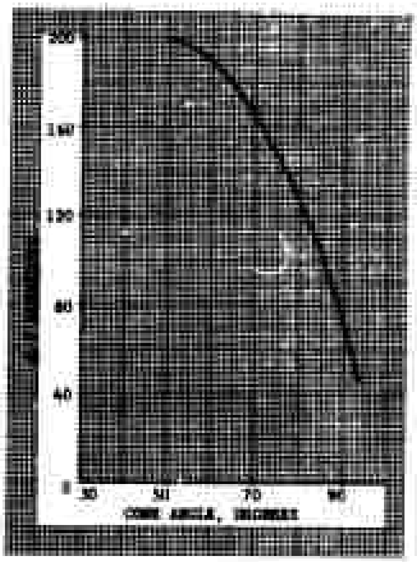


Figure 3. Bandwidth of Biconical Antenna, Radius 250 ft., Freq. 100 KHz, as a Function of Cone Angle (Efficiency = 1)

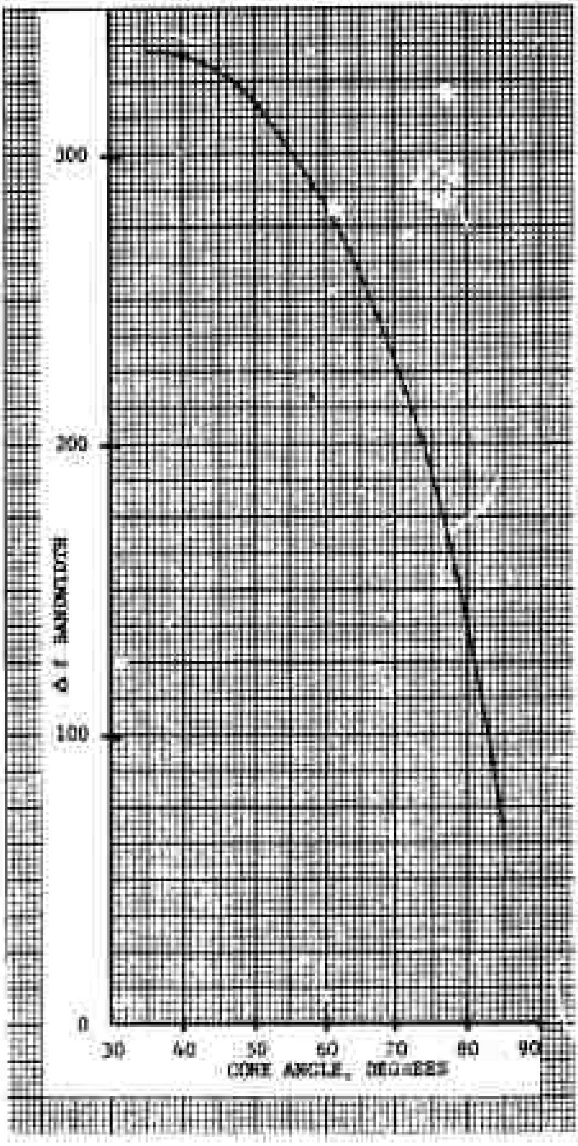


Figure 4. Bandwidth of Biconical Antenna of 300 ft. Radius at 100 Kilohertz as a Function of Cone Angle (Efficiency = 1)

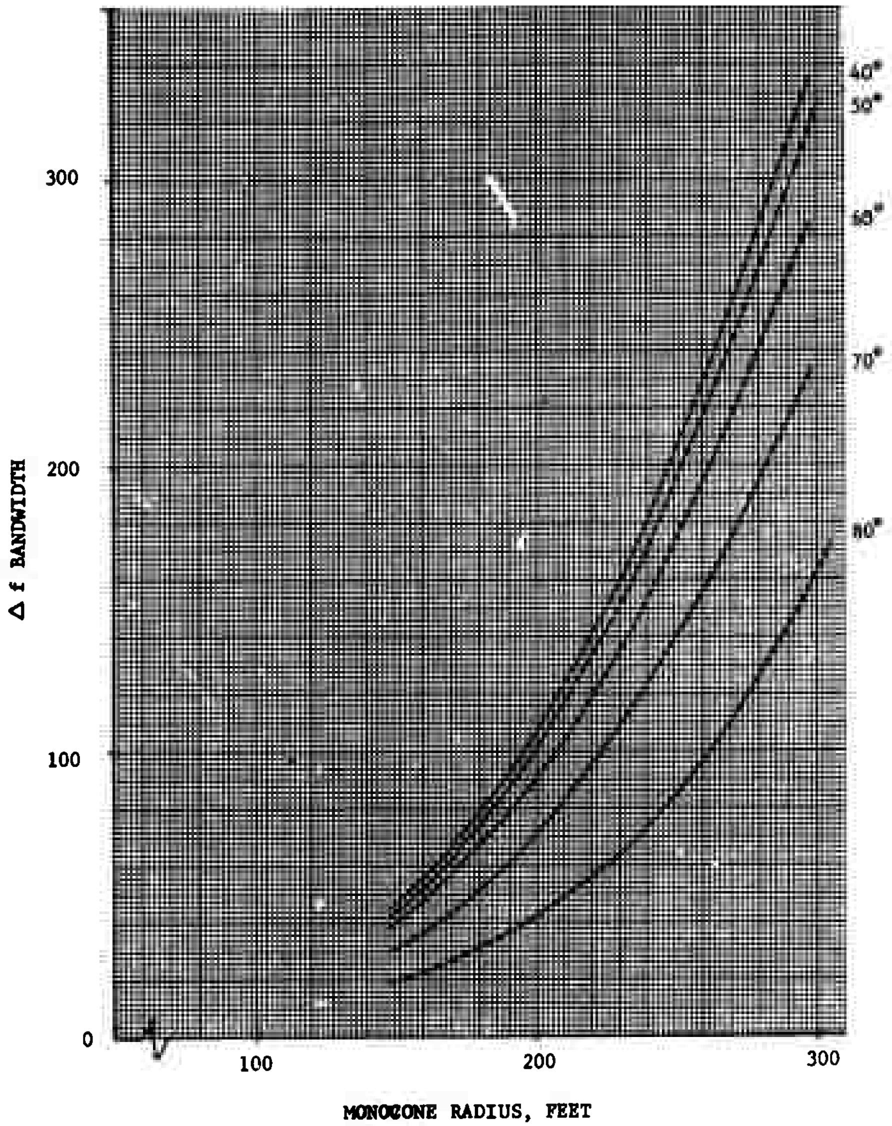


Figure 5. Bandwidth of Monocone Antennas as Function of Radius, or Height, at 100 KHz. Cone Angle as Parameter

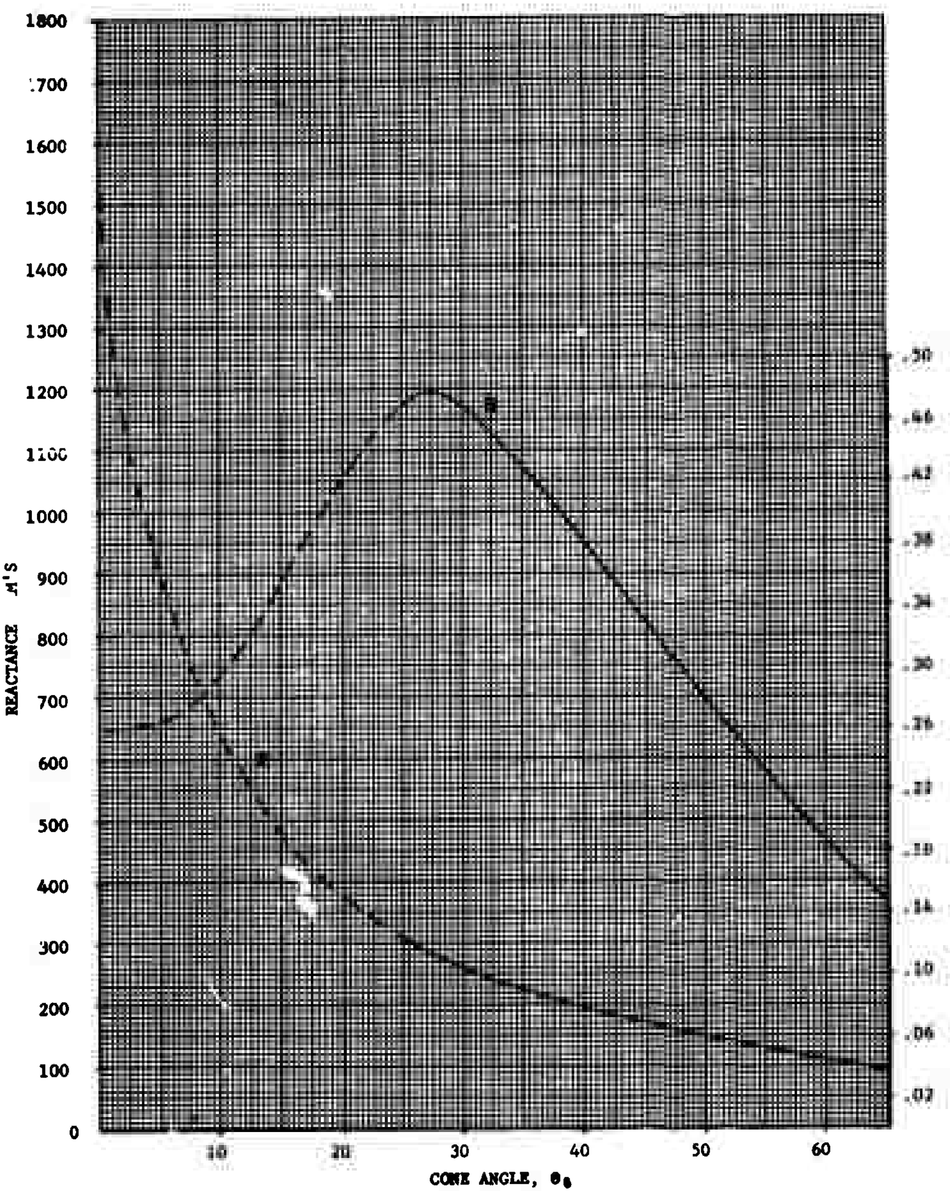


Figure 6. Input Impedance of 250 ft. Monocone Antenna at 100 KHz, as a Function of Cone Angle

TABLE IV. TERMINATING ADMITTANCE AND INPUT IMPEDANCE @ 100 KHz FOR 250 FOOT RADIUS BICONES VS. CONE ANGLE

θ	250'			
	Y_T Real	Y_T I_m	Z_{in} Real	Z_{in} I_m
35	4.19 by 10^{-6}	1.05 by 10^{-3}	8.78 by 10^{-1}	-4.41 by 10^2
45	5.35 by 10^{-6}	1.35 by 10^{-3}	6.65 by 10^{-1}	-3.40 by 10^2
55	6.42 by 10^{-6}	1.69 by 10^{-3}	4.70 by 10^{-1}	-2.61 by 10^2
65	7.31 by 10^{-6}	2.10 by 10^{-3}	2.92 by 10^{-1}	-1.94 by 10^2
75	7.94 by 10^{-6}	2.64 by 10^{-3}	1.37 by 10^{-1}	-1.28 by 10^2
85	8.27 by 10^{-6}	3.63 by 10^{-3}	2.33 by 10^{-2}	-5.23 by 10^1

TABLE V. TERMINATING ADMITTANCE AND INPUT IMPEDANCE @ 100 KHz FOR 300 FOOT RADIUS BICONES VS. CONE ANGLE

θ	300			
	Y_T Real	Y_T I_m	Z_{in} Real	Z_{in} I_m
35	8.78 by 10^{-6}	1.27 by 10^{-3}	1.27	-3.61 by 10^2
45	1.12 by 10^{-5}	1.64 by 10^{-3}	9.65 by 10^{-1}	-2.78 by 10^2
55	1.35 by 10^{-5}	2.05 by 10^{-3}	6.82 by 10^{-1}	-2.14 by 10^2
65	1.33 by 10^{-5}	2.34 by 10^{-3}	4.24 by 10^{-1}	-1.59 by 10^2
75	1.66 by 10^{-5}	3.19 by 10^{-3}	2.00 by 10^{-1}	-1.05 by 10^2
85	1.73 by 10^{-5}	4.42 by 10^{-3}	3.43 by 10^{-2}	-4.33 by 10^1

maximum value at about 28 degrees. Considering the biconical portion of the antenna as a monopole, the spherical cap provides capacitive loading to this monopole. As the cone angle increases from small values the loading increases but the effective height of the monopole portion decreases, thus providing the peak in the resistance curve.

Practical monocone structures consist of a cage of equally spaced wires on a conical surface. Also, the top or "cap" consists of an inverted cone composed of the same wires in lieu of a solid spherical cap. In general, the inverted cage has a different angle than that of the biconical section. Because of this top section, in particular, the impedance and hence the η XBW of the case will be different than that for the solid cones.

TABLE VI. TERMINATING ADMITTANCE AND INPUT IMPEDANCE @ 100 KHz FOR 350 FOOT RADIUS BICONES VS. CONE ANGLE

θ	350'			
	Y_T Real	Y_T I_m	Z_{in} Real	Z_{in} I_m
35	1.65 by 10^{-5}	1.51 by 10^{-3}	1.75	-3.03 by 10^{2}
45	2.10 by 10^{-5}	1.94 by 10^{-3}	1.33	-2.33 by 10^{2}
55	2.52 by 10^{-5}	2.42 by 10^{-3}	9.39 by 10^{-1}	-1.80 by 10^{2}
65	2.87 by 10^{-5}	2.99 by 10^{-3}	5.84 by 10^{-1}	-1.34 by 10^{2}
75	3.12 by 10^{-5}	3.76 by 10^{-3}	2.76 by 10^{-1}	-8.91 by 10^{1}
85	3.25 by 10^{-5}	5.19 by 10^{-3}	4.74 by 10^{-2}	-3.68 by 10^{1}

The cage of wires having angle θ can be transformed into an equivalent cone having angle θ_e according to Schelkunoff[7]. The relation is given by

$$\tan\left(\frac{1}{2}\theta_e\right) = \tan\left(\frac{1}{2}\theta\right)\left[\frac{n\tan\left(\frac{1}{2}\theta_o\right)}{\tan\left(\frac{1}{2}\theta\right)}\right]^{\frac{1}{n}}$$

where

θ_o is the cone angle of the conical wire.

n is the number of wires.

The geometry of a wire cage monocone is shown as figure 7. The relation between the cone and cage angles for n equal 6, 12, 24 and for θ_o equal to $1X10^{-4}$ is shown as figure 8.

The cases to be considered are those where lengths of the monocone wires are equal to the height; that is

$$\frac{h_m}{\cos\theta_B} = h_T .$$

The model used is that of considering the top inverted cage to serve as a load on a section of biconical transmission line. The load reactance, Z_L, is given by

$$Z_L = -j\, Z_o \cos\beta\, Z$$

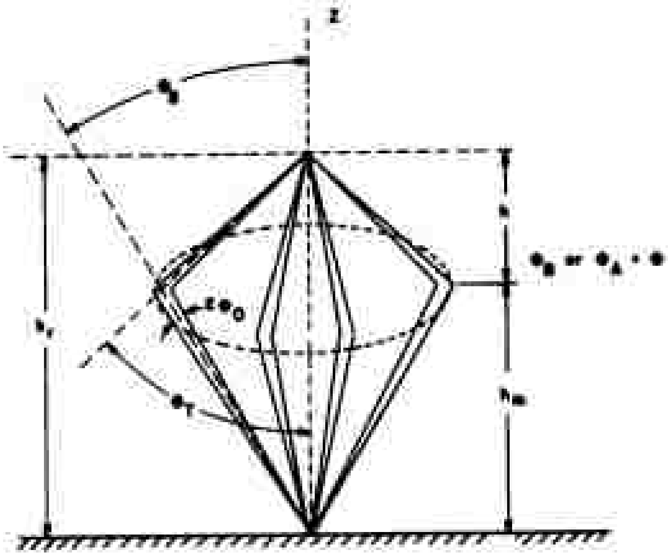


Figure 7. Geometry of Wire Cage Monocone

where Z_0 is the average characteristic impedance of the inverted cone section.

$$Z_o \approx \frac{60}{h} \int_o^h \ln \left[\frac{2\, Z\, d\, z}{(h-z) \sin \theta_{et}}\right] dz$$

$$= 60 \ln \left(\frac{2}{\sin \theta_{et}}\right)$$

where θ_{et} is equivalent cone angle for the top inverted section. The current of the bi-conical line section projected onto the Z axis is given by

$$I_{(z)} = I_z \left(e^{+j\beta\,(h_m - z)} - \rho_{hm}\, e^{-j\beta\,(h_T - z)}\right)$$

$$0 \leq Z \leq h_m$$

with the phase referred to the load end.

where ρ_{hm} is the load reflection coefficient.

$$\rho_{hm} = \frac{Z_L - Z_{0B}}{Z_L + Z_{0B}} = 1\, e^{j \arg \rho_{hm}}$$

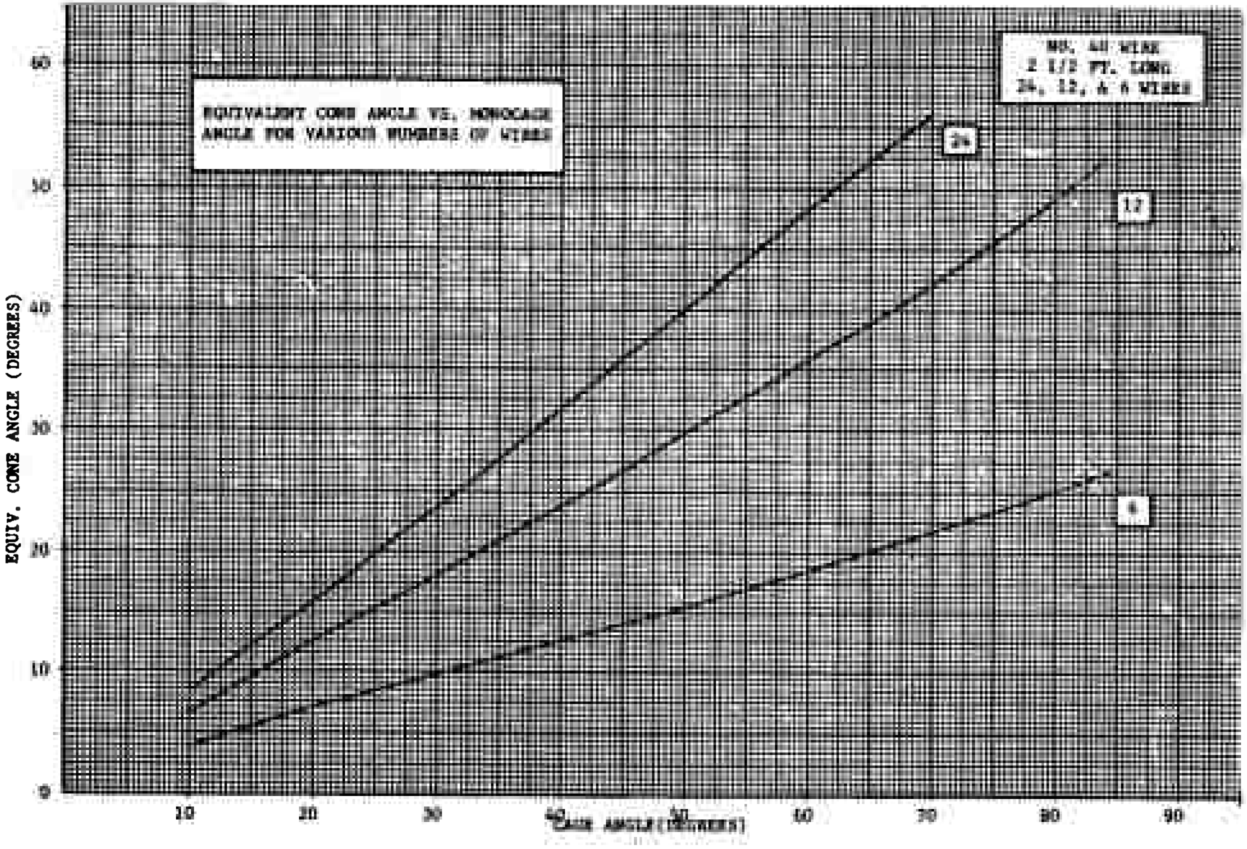


Figure 8. Equivalent Cone Angle vs. Monocage Angle for Various Numbers of Wires

where

$$Z_{0B} = 60 \ln \left(\cot \frac{\theta_{eB}}{2}\right)$$ the biconical line characteristic impedance

θ_{eB} is equivalent cone angle at the biconical section.

$$I_z = \frac{1}{1 - \rho_{hm}}$$

Then

$$|I_z| = |I_2| \sqrt{2} \sqrt{1 - \cos\left[\arg \rho_{hm} - 2\beta\left(h_m - z\right)\right]}$$

The average current over this sector referred to the total height, h_T, is

$$I_{ave} = \frac{1}{\beta h_T} \int_0^{h_m} |I_z| \, d\beta z$$

$$= \frac{2|I_2|}{\beta h_T} \left[\cos\left(\frac{\arg \rho h_m}{2} + \beta h_m - \beta z\right)\right] \Bigg|_o^{\beta h_m}$$

If the current projection of the top inverted cone on the Z axis is assumed to be linear, the average current on this sector is given simply by

$$I_{ave} = \frac{.5\left(\beta_{h_T} - \beta_{h_m}\right)}{\beta_{h_T}}$$

The assumption of a linear variation of current is not strictly correct as the current is really much larger near the base of the inverted cone than further out. The result is that the effective height of the monocage calculated is a little high, but this is significant only for large base cone angles. The effective height is given by

$$\frac{h_e}{h_T} = 2|I_2| \left[\cos\left(\frac{\arg \rho h_m}{2} + \beta h_m - \beta z\right)\right] \Bigg|_o^{h_m} + \frac{.5\left(\beta h_T - \beta h_m\right)}{|I_o| \beta h_T}$$

where

$$I_o = |I_2| \sqrt{2} \sqrt{1 - \cos\left(\arg \rho h_m + 2\beta h_m\right)}.$$

The input resistance is then given by

$$R_a = 40\,(\beta\, h_T)^2 \left(\frac{h_e}{h_T}\right)^2 .$$

Resistances were calculated for h_T equal 250 feet, n equal to 6, 12, 24 for angles θ_B from 20-60 degrees. These resistance values are shown in Table VII. For the calculated impedance curves of figure 6 for the perfect solid bicone, the η XBW's vs. cone angle calculated and are shown in figure 9. Also plotted in this graph is the calculated η XBW using the same resistance values but reactance values corresponding to the equivalent cone angle for 12 wires and the measured monocage data for 12 wires. If the difference between the latter two sets of data is used to correct the resistance curve of figure 6, the corrected curve and the values calculated in Table VII for twelve wires correspond closely. This comparison is shown in figure 10.

The transmission line model used to compute effective height can also be used to compute reactance. As stated previously, the load reactance on the biconical line is given by

$$Z_L = -j\,60 \cot \beta\, h \ln\left(\frac{2}{\sin \theta_{eT}}\right)$$

$$\approx -j\,\frac{60}{\beta\, h} \ln\left(\frac{2}{\sin \theta_{eT}}\right).$$

The input reactance is then given by

$$X_a = \frac{-j\,\dfrac{Z_L}{Z_{oB}} + j\,\beta\, h}{1 + \beta\, h\left(\dfrac{Z_L}{Z_{oB}}\right)}.$$

TABLE VII. MONOCAGE IMPEDANCE CALCULATED USING THE "IMPEDANCE CONCEPT" FOR 250 FOOT RADIUS; 24, 12, 6 WIRES @ 100 KHz VS. CAGE ANGLE

θ_o	6 Wires		12 Wires		24 Wires	
	R	-jX	R	-jX	R	-jX
20	0.282	820	0.295	726	0.297	631
30	0.287	770	0.289	542	0.306	462
40	0.277	625	0.253	437	0.296	349
50	0.262	529	0.241	348	0.256	272
60	0.257	449	0.205	284	0.217	211

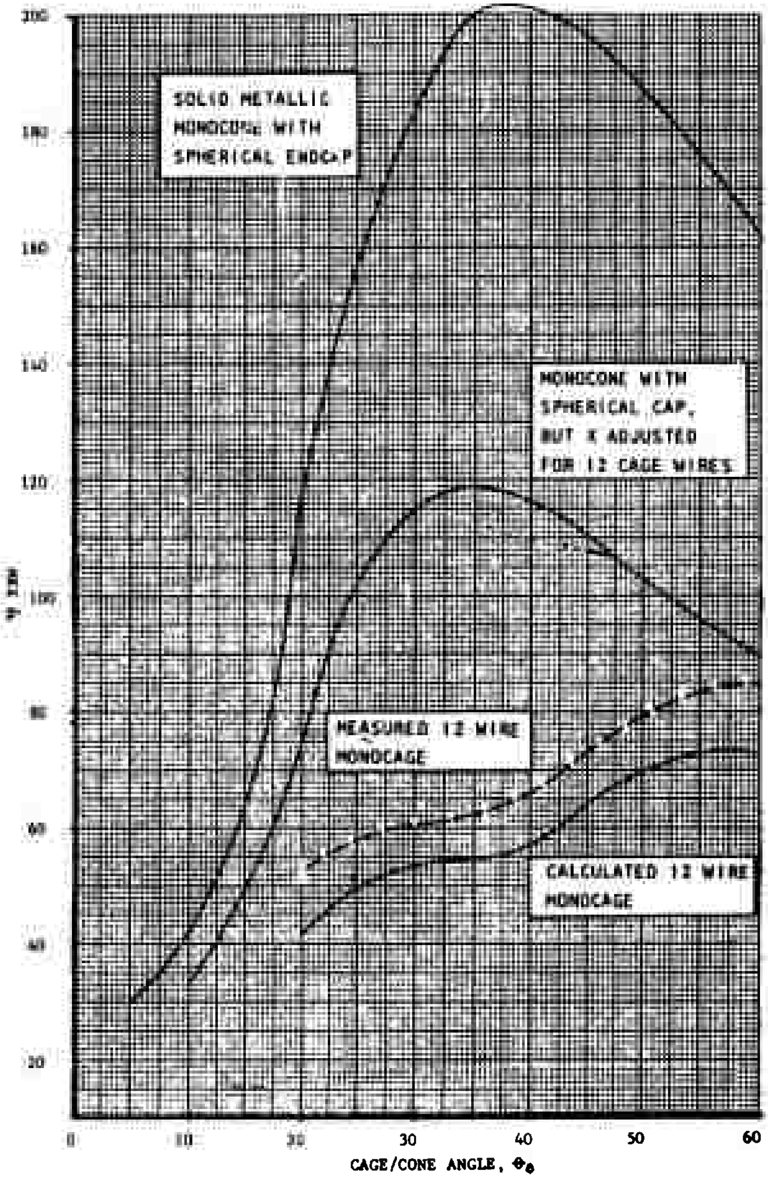


Figure 9. Comparison of the ηXBW of a 250 ft Monocone and a 250 ft Monocage at 100 KHz as a Function of Angle for 100% Efficiency

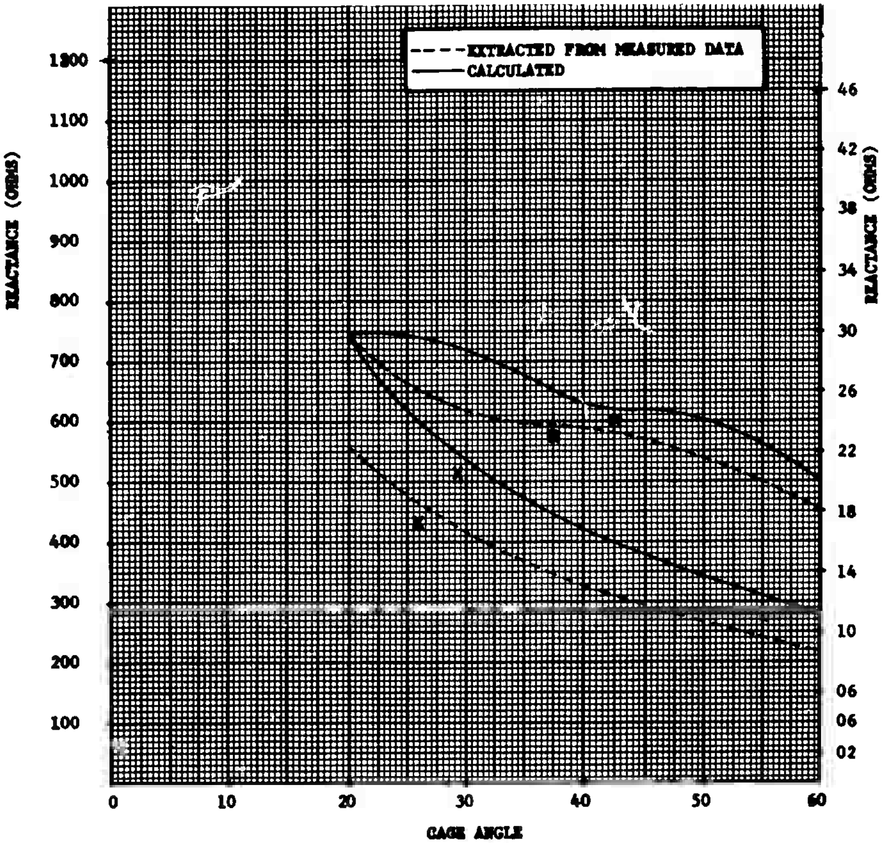


Figure 10. Comparison of Input Impedance Calculated for Monocage and Extracted from Measured Data

These reactances were also calculated for h_T equal 250 feet, n equal to 6, 12, 24 for angles θ_B from 20-60 degrees and are tabulated together with the previous resistance values in Table VII. From these resistances and reactances, ηXBW were calculated and are shown in figure 11. The case for 9 wires is also plotted in figure 11 as a comparison with the measured values.

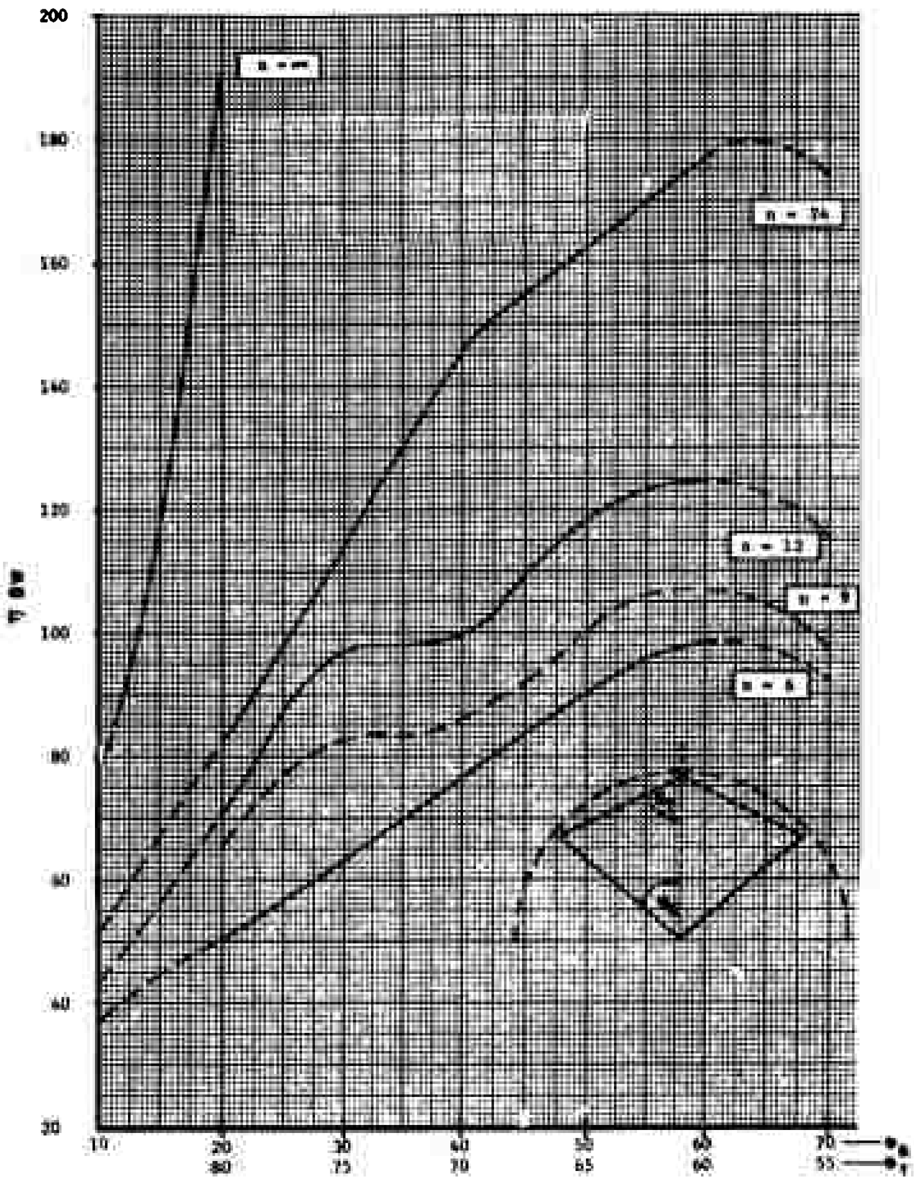


Figure 11. ηXBW for Monocage as a Function of Number of Wires

Although the ηXBW is shown to increase for an increase in the base cone angle, θ_B, the values must go through a maximum and then decrease. For low number of wires the maximum is nearly reached at θ_B equals 60 degrees. For very large base cone angles, the method used to calculate the ηXBW becomes inaccurate due to not knowing the current distribution on the "inverted cone" portion of the antenna with accuracy. Using a value of h_e/h_T equals 0.42 determined from data calculated for 12 wire umbrella antennas[8], the best estimate of ηXBW is about 50. With this value in mind, the ηXBW curves of figure 11 were extrapolated and replotted, in a form to facilitate comparison later in the report, in figure 12. Also plotted is the ηXBW for the perfect monocone, the data for which was established earlier in this section for large cone angles. The maximum ηXBW for the perfect monocone occurs for a different cone angle than for the wire cage structures because of the difference in the "end cap".

(2) Umbrella Standard Model

There are several sources of wire umbrella data available for use in establishing the ηXBW to use as a standard of comparison. Unfortunately, most of the sources containing either measured or calculated data are either too sketchy or unsuited to the electrical size requirements for Loran-D. These sources of data are:

(a) Space General Report SGCTM1A-12[8]

(b) Smith-Johnson Paper[9]

(c) Navy Report (unpublished at this time)[10]

The problem of establishing a reference level for ηXBW is further complicated by the fact that there is no way to calculate exactly the ηXBW; and considering the methods used, there is a considerable spread between the results of these calculations and measured data. Calculations performed external to the present work are based upon static field analysis where the static charge distribution is calculated over the antenna conducting surface allowing the determination of static input capacitance and effective height based on this distribution of charge. This analysis considering the antenna to be infinitesimally electrically small, which is not exact. An alternate approximate method of analysis is based on the "impedance concept" employed in sub-section 1 preceding. In this case the resistance was estimated from an effective height calculation based on a transmission line model representing the projected vertical current distribution. A more accurate method of obtaining the resistance, which is beyond the scope of this work, would be the use of Schelkunoff's[11] "method of moments".

Using the impedance concept, the inverted wire cone (umbrella wires) and the "masked" portion of the tower are considered to load the unmasked portion of the tower. As before, the load reactance of the inverted cone section is given by

$$X_L \approx -j \frac{60}{\beta\,(h_T - h_m)} \ln \frac{2}{\sin \theta_{eT}}$$

where (as shown in figure 13)

h_T is the total tower height

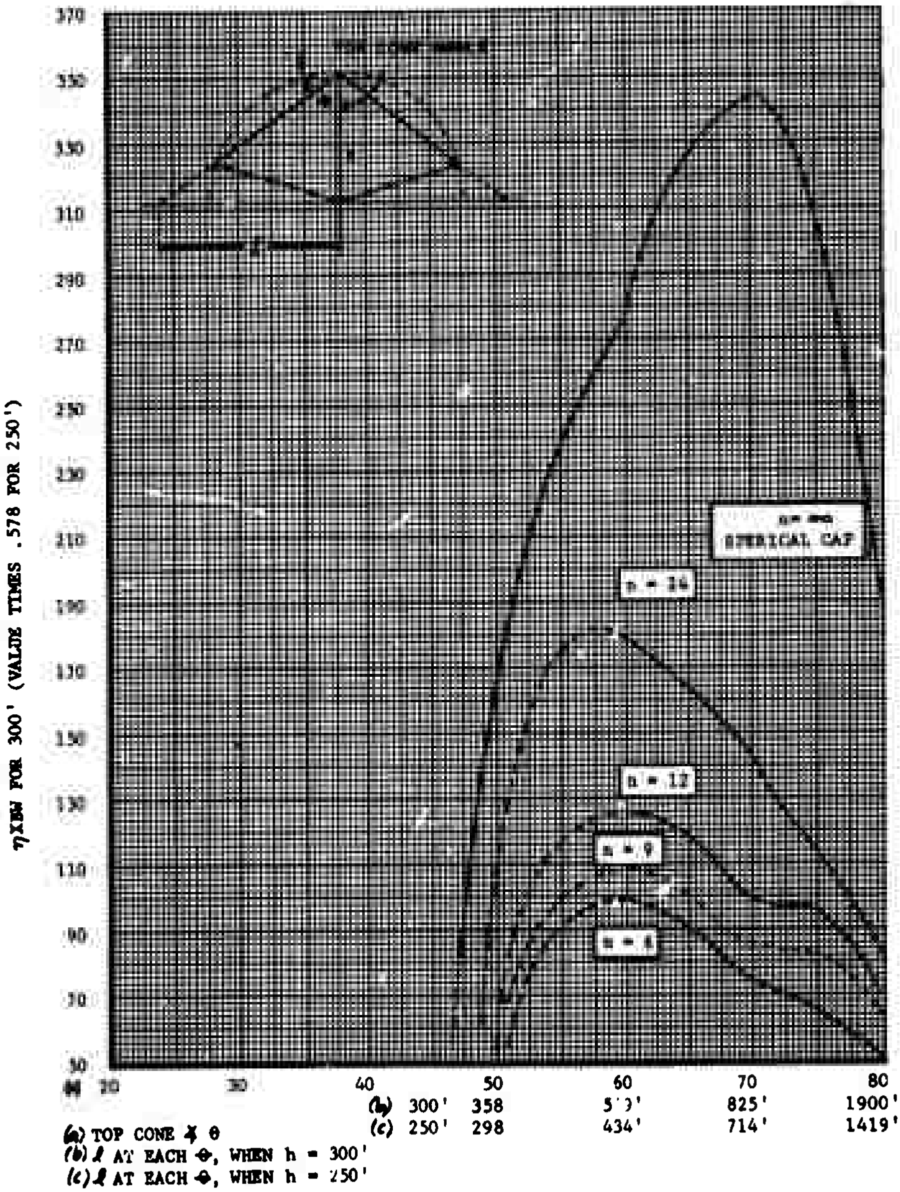


Figure 12. ηXBW for 300 ft. Monocage Antenna vs. Top Cone Angle

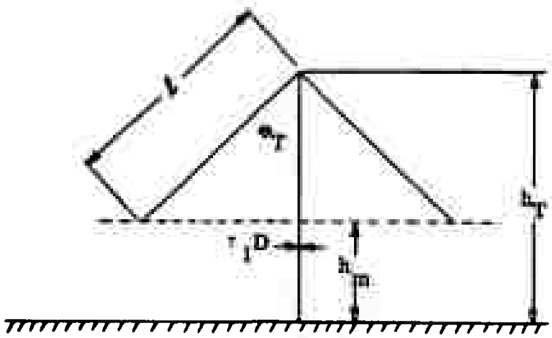


Figure 13. Geometry of Wire Umbrella Antenna

h_m is the unmasked tower height.

In addition, the equivalent series inductive reactance represented by the masked portion of tower encased by the umbrella wires is given by

$$X_m \approx +j\,30\,\beta\,(h_T-h_m)\left[\ln\left(\frac{\ell}{2r}\sin\theta_{eT}\right)+1\right]$$

where

ℓ is the umbrella wire length

r is the tower radius.

In the same notation used in the previous section,

$$Z_L = X_L + X_m .$$

Instead of using the characteristic impedance of the biconical line for the line loaded by Z_L, the average characteristic impedance of the unmasked portion of mast is used which is given by

$$Z_o = 60\left[\ln\left(\frac{4\,h_m}{D_m}\right)-1\right]$$

where

D_m is the mast diameter.

Using the impedance concept, ηXBW were calculated for θ_T equals 49 degrees, h_T equals 300 feet, n = 12 for varying ℓ/h_T. The results are plotted in

figure 14. Figure 14 shows a comparison of ηXBW for the above parameters using available calculated and measured data. Included on this graph are:

(a) ηXBW from impedance concept.

(b) ηXBW measured as part of this program.

(c) ηXBW using resistance from impedance concept and measured reactances.

(d) ηXBW from Space General report based on static computations.

(e) ηXBW from Navy report based on static computations.

(f) ηXBW from Smith Johnson scaled up from n equals 8 to n equals 12 using Navy computations as a basis.

The hybrid calculation of (c) above was made because the reactance values measured were in general agreement with those of the static's calculations of (d) and (e). In the range of ℓ/h_T for maximum ηXBW, there is a spread of about 20 percent in ηXBW. The results of the Navy report were weighed quite heavily because the report contains detailed calculations of ηXBW versus the various umbrella parameters.

The Navy report presents ηXBW in normalized form with respect to the ηXBW of the tower alone. For a tower with a length-to-diameter ratio of about 100- and 300-feet tall at 100 KHz, the resistance, reactance, and ηXBW are respectively about .367 ohm, -j1600 ohm, 23.2. Regardless of whether or not the ηXBW versus parameters from the Navy report are correct in an absolute sense, it is very reasonable that the relative variations are correct. ηXBW versus ℓ/h_T for various numbers of wires is given in figure 15. ηXBW, optimized for ℓ/h_T, are given versus umbrella angle, θ_T, in figure 16. The data on these latter two figures were plotted relative to the Navy report with respect to a value of 136 chosen on the basis of the data of figure 14. The values of figure 16 are hereby chosen as being the standard of comparison for the remainder of the report.

(3) Transmission Line Model

The transmission line model is of interest because a wide class of antenna types fit into this category. Also, the analysis differs sufficiently from that of the axially-symmetric conical antenna types, such as the umbrella and monocone, to provide a slightly different point of view. The transmission line antenna consists of a vertical mast loaded in some manner at the top with a transmission line. Generally this line lies in a plane parallel to the ground and at the height of the tower.

It is intuitively obvious that high ηXBW can be achieved with transmission line antennas if the line is made sufficiently long. The problem is that of determining the ηXBW (i.e., capacity of the line) which is practical to achieve within the land area limitations posed by the transportable Loran-D System.

The capacity achievable with any open-circuited line configuration at a fixed height above ground is greatest for the greatest conductor area which can be presented by the line. For this reason, and to place an upper bound on the ηXBW for transmission line antennas, the case of an axially symmetric disc placed on top of a

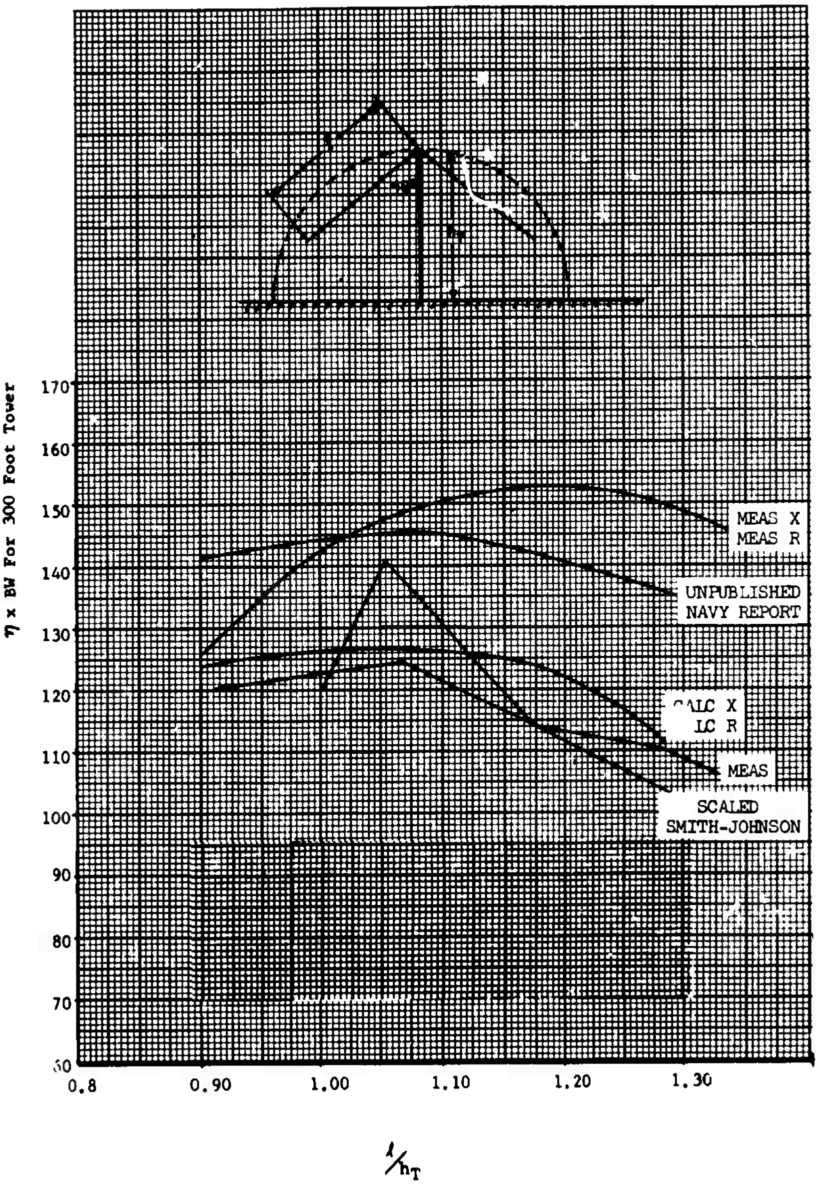


Figure 14. Comparison of Efficiency Bandwidth Product for Twelve Wire, 49 Degree Umbrella for Various Literature Sources; Also Calculated and Measured Values, This Contract

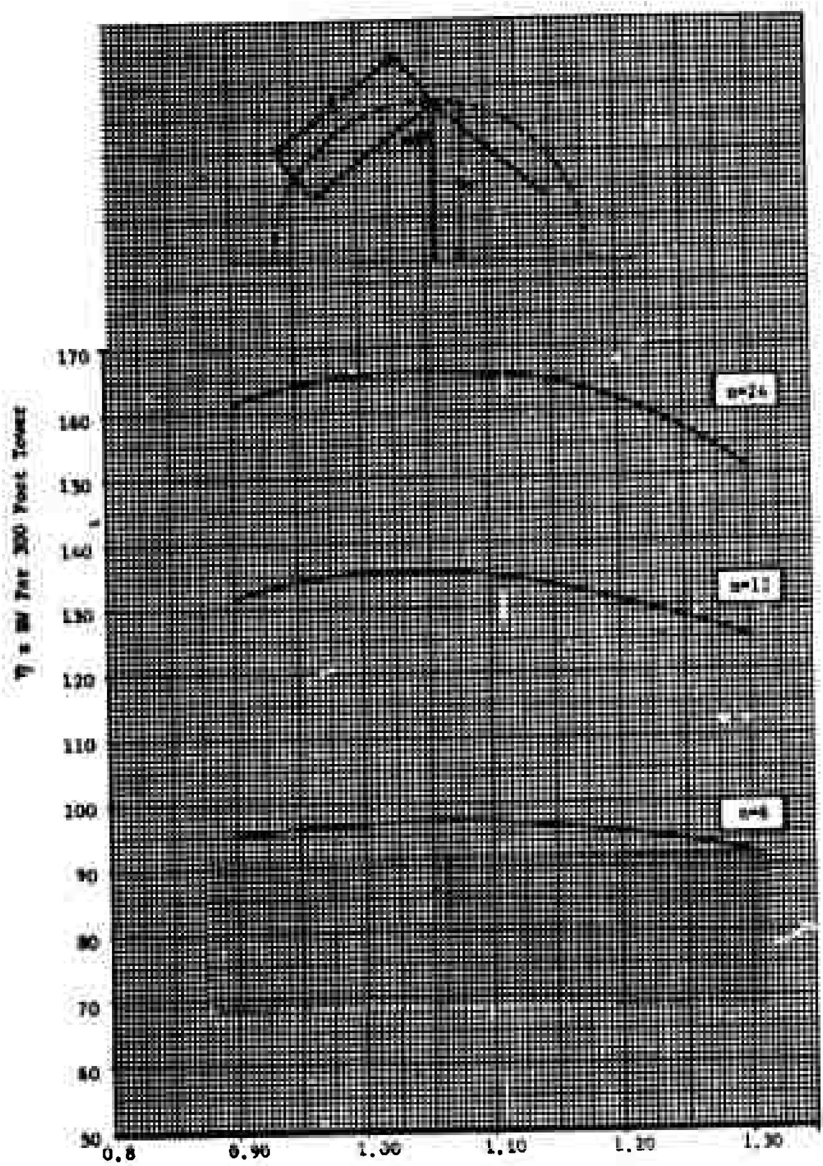
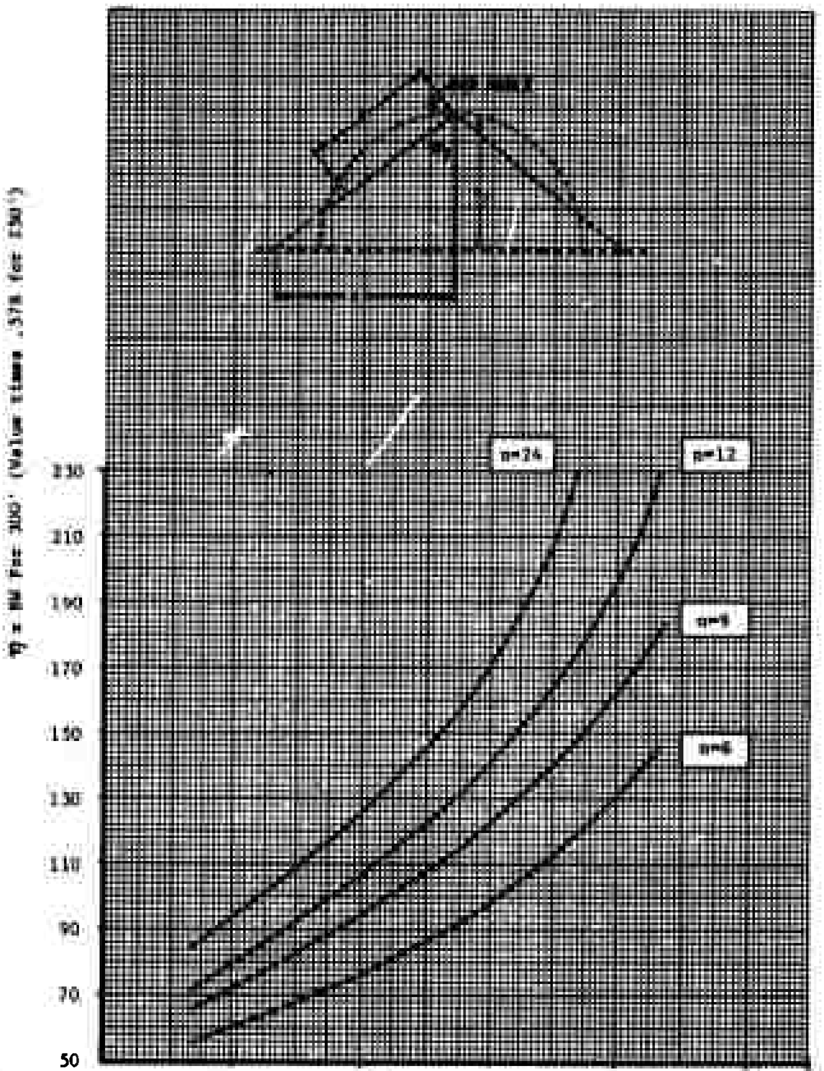


Figure 15. Efficiency-Bandwidth Product @ 100 KHz for Wire Umbrella, Mast h/d = 96, Wire ℓ/d = 10,000, θ_T = 49 Degrees vs. Number of Wires



Top ∡ θ	20°	30°	40°	50°	60°	70°
r at each θ, when h_T=300'			300'	358'	519'	825'
r at each θ, when h_T=250'			250'	298'	434'	714'

Figure 16. Efficiency-Bandwidth Product @ 100 KHz for Wire Umbrella, Mast h/d = 96, Wire ℓ/d = 10,000, ℓ/h_T Adjusted for Maximum vs. Number of Wires

mast will first be considered. This disc forms a radial transmission line with respect to the tower and this line presents maximum conductor area for a fixed height above ground. The geometry of this antenna is shown in figure 17.

The load reactance presented to the mast by the disc is given by[12]

$$X_L = -j\, Z_{oi} \frac{\cos(\theta_i - \psi_L)}{\sin(\psi_i - \psi_L)} = \frac{h}{2\,\pi_r} \frac{E_z}{H_\phi}\Bigg|_i$$

with output of the radial line short circuited, where Z_{oi}, θ_i, ψ_i are quantities evaluated at the input radius. ψ_L is a quantity evaluated at the disc radius.

$$Z_{oi} = 60\,\frac{h}{r}\,\frac{|H_0(k_r)|}{|H_1(k_r)|}\Bigg|_{\text{input radius}}$$

where

h = mast height

r = radius

H_o, H_1, are Hankel functions of first or second kinds of zero and first orders.

That is,

$$|H_o^{(1)}(k_r)| = |H_o^{(2)}(k_r)| = \left[J_o^2(k_r) + N_o^2(k_r)\right]^{1/2}$$

$$|H_1^{(1)}(k_r)| = |H_1^{(2)}(k_r)| = \left[J_o^2(k_r) + N_o^2(k_r)\right]^{1/2}$$

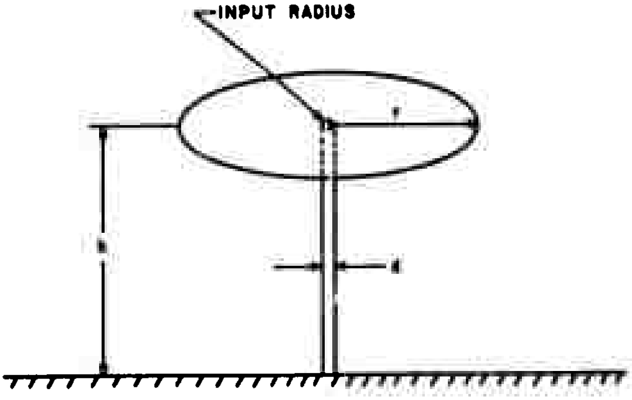


Figure 17. Geometry of Disc Loaded Tower

where $J_n(k_r)$, $N_n(k_r)$ are the usual Bessel functions of 1st and 2nd kinds. Also,

$$\theta(k_r) = \tan^{-1}\left[\frac{N_o(k_r)}{J_o(k_r)}\right]$$

$$\psi(k_r) = \tan^{-1}\left[\frac{J_1(k_r)}{-H_1(k_r)}\right]$$

For purposes of analysis, a mast of $k_h = 0.128$, (200 feet @ 100 KHz) $k_r = 0.00064$ (2 feet @ 100 KHz) was chosen. For evaluation of Z_{oi}, small argument approximations apply for the Bessel Functions, and as a result

$$Z_{oi} \approx 60\, k_h \ln\left(\frac{2}{1.781\, k_r}\right).$$

Once the load reactance, X_L, is known, the input reactance, X_a, is given by the usual transmission line formula

$$X_a = Z_{oa} \frac{X_L \cos kh + j\, Z_{oa} \sin kh}{Z_o \cos kh + j\, Z_L \sin kh}$$

where Z_{oa} is the average characteristic impedance of the mast previously defined.

The radiation resistance of the mast is calculated by the method used in the preceding two subsections. Some radiation resistance is associated with the transmission line portion of the antenna, but this resistance is ignored because we are concerned only with the vertically polarized surface wave. The ηXBW is calculated by the simple formula

$$\eta XBW = \frac{f\, R_r}{X_a}.$$

The calculated radiation resistance is shown in figure 18 and the ηXBW vs. k_r is shown in figure 19.

For a simple, but general approach for ηXBW applicable to transmission line antennas, consider the bandwidth to be given by

$$BW = \Delta f = \frac{2\, R_r\, f_o}{f_o \left.\frac{dX_a}{df}\right|_{f_o} + X_a}$$

If the reactance, X_a, is given by

$$X_a = -j\, Z_o \cot\left(\frac{\pi}{2} \frac{f}{f_R}\right)$$

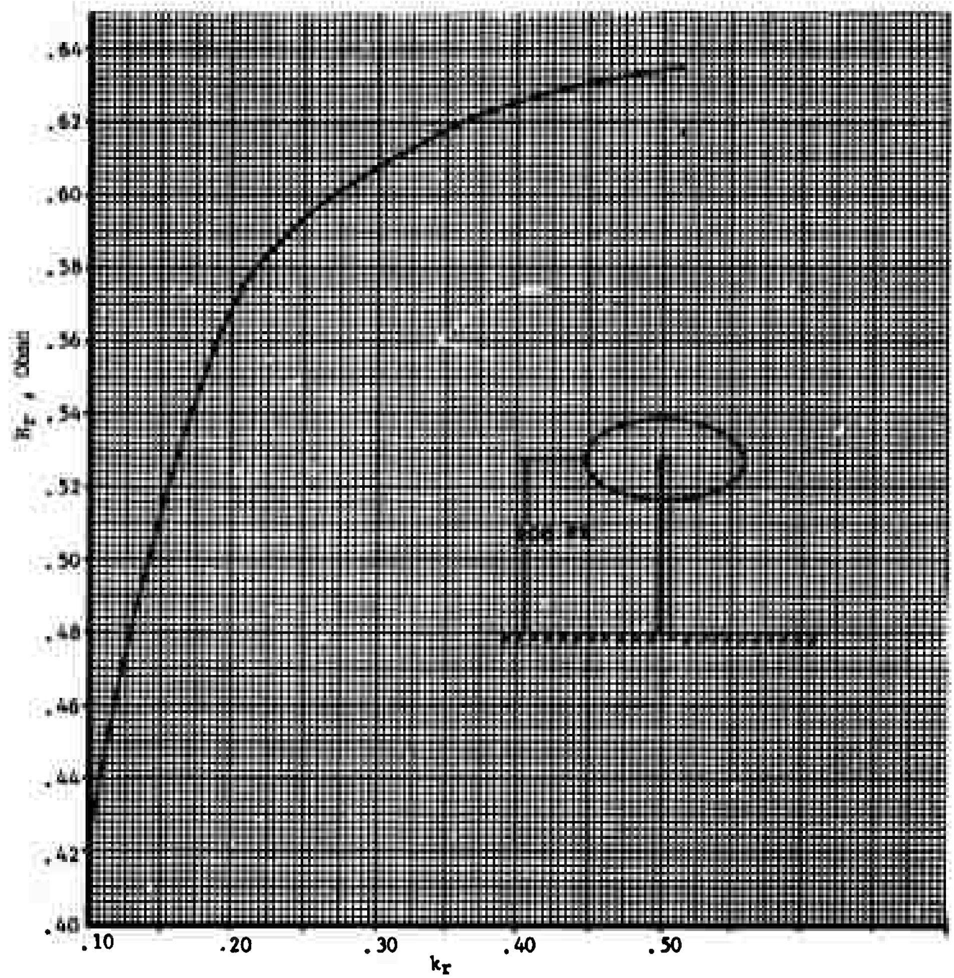


Figure 18. Radiation Resistance of Disc-Loaded Tower vs. Disc Radius @ 100 KHz

where

Z_o is the characteristic impedance at the line

f_R is the series resonant frequency,

then

$$\frac{dX_a}{d_f} = Z_o \frac{\pi}{2f_R \sin^2\left(\frac{\pi}{2}\frac{f}{f_R}\right)}$$

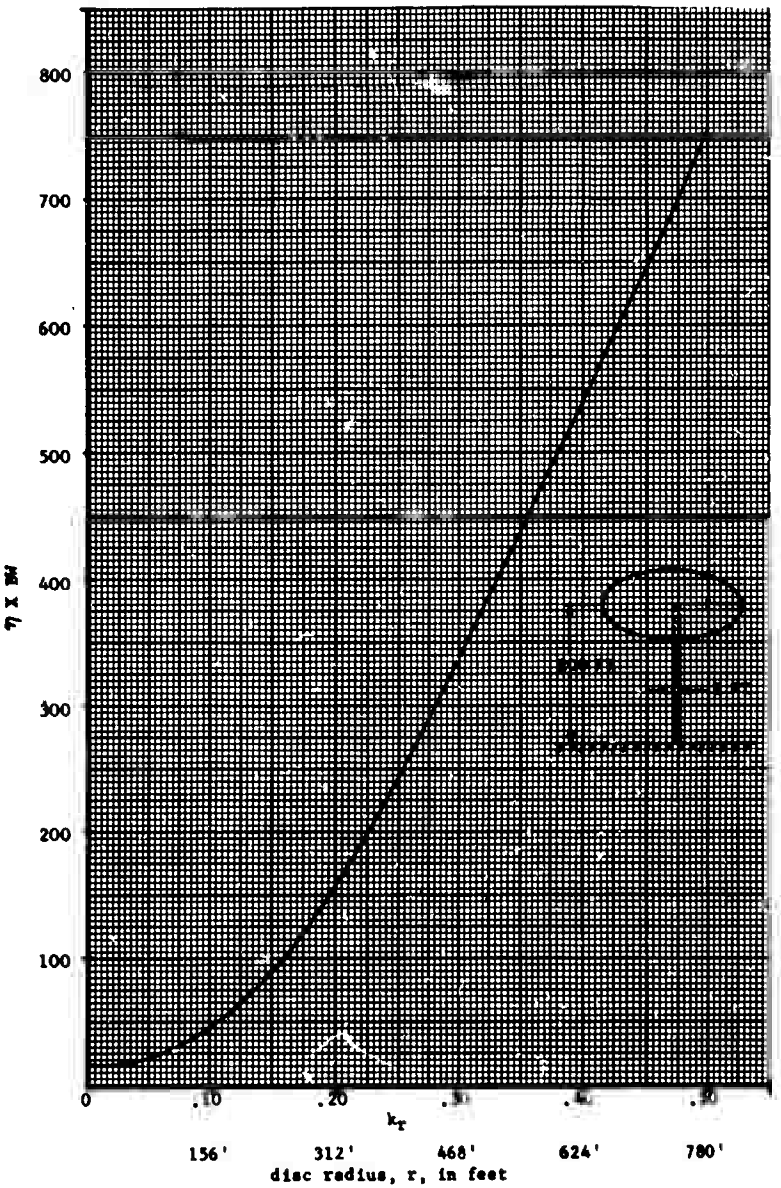


Figure 19. Efficiency-Bandwidth Product of Disc Loaded Tower vs. Disc Radius @ 100 KHz

and

$$\eta XBW = \frac{2R_r\, f \sin^2\left(\frac{\pi}{2}\frac{f}{f_R}\right)}{\frac{f\,Z_o}{2f_R} + \frac{Z_o}{2}\sin\left(\pi\frac{f}{f_R}\right)}$$

with

$$\frac{4\ell}{\lambda} = \frac{f}{f_R},$$

ℓ being the line length,

$$\eta XBW = \frac{2R_r \sin^2 k\ell}{k\ell\; Z_o + \frac{Z_o}{2}\sin 2k\ell}.$$

For electrically short lines,

$$\eta XBW = \frac{\pi}{2}\frac{f^2}{f_R}\frac{R_r}{Z_o} = \frac{k\ell\; f\, R_r}{Z_o}.$$

For lines near series resonance,

$$\eta XBW = \frac{4\, fR_r}{\pi\, Z_o}$$

As an example, consider a ring antenna as depicted in figure 20 using the same tower height and ℓ/D as for the disc loaded antenna (200 feet, $\ell/D = 100$). The ring radius was chosen at 300 feet and R_r was chosen as 0.65 ohms (near-uniformly loaded).

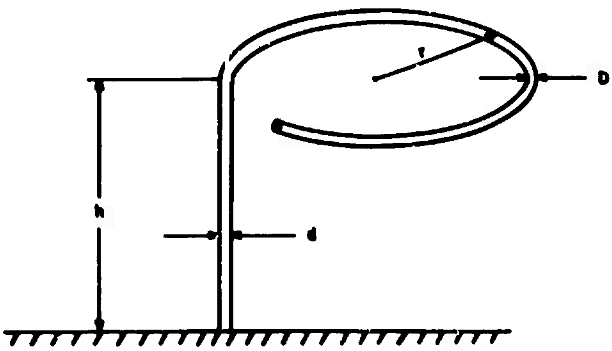


Figure 20. Geometry of Ring Antenna

ηXBW was calculated as a function of ring diameter and correspondingly the total conductor area contained in the ring given as

$$\text{Area} = 2\pi^2 d\ (300) \text{ in square ft.}$$

The results are plotted as figure 21. A ring with diameter d is equivalent to a flat strip with width twice the ring diameter.

(4) Summary of Analytical Work

In subsections (2) and (3) are illustrations summarizing the results of the ηXBW calculations (figure 12 for monocones, figure 16 for umbrellas). These figures are plotted to the same scale so that they may be compared by inspection. These curves show that for a given tower height and top cone angle, θ_T, for a given number of wires, the umbrella is always superior to the monocone. As the monocone is constrained to a 300-foot hemisphere, the only point for exact comparison is at an angle of 60 degrees, however, with the aid of figures 14 and 15, this result is verified for other values of θ_T as well. The reason the umbrella is better is because its effective height and, hence, radiation resistance is greater. This is true even though the monocone has a lower input reactance. For example, at 60 degrees ηXBW's are about 125 and 194 for the monocone (monocage) and umbrella respectively if n = 12. For those cases the resistances are about 0.295 and 0.652 ohms respectively. Because the monocage is a more complex antenna, it is hereby eliminated from further consideration as an optimum design.

Several interesting facts are apparent upon examining the results of the transmission line antenna model. First, the impracticability of constructing a suitable disc-loaded tower is demonstrated by considering figure 19. For a ηXBW of 100 using a 200-foot tower, a disc with radius of 250 feet is required. To make the construction comparable with that of an umbrella, consider figure 22, where a 300 foot mast is used to guy off and support a disc at the 200-foot level. It is seen that a land area 625 feet in radius is required.

Consider a 300-foot disc loading a 200-foot tower. The area of this disc is 283,000 square feet. The corresponding ηXBW is 150. From the curve of figure 22, the conductor area of a ring antenna to give a ηXBW of 150 is 302,000 square feet and the ring diameter would have to be 51 feet. This example clearly demonstrates the effect of conductor area on the ηXBW of a transmission line antenna. For the land area available, it is clear that the umbrella antenna, properly designed, will give superior performance over the transmission line antenna. If real estate were no problem, a transmission line antenna may well be the best choice.

The results of the electrical analysis indicate that the optimum antenna configuration is the umbrella. The goal of this section is then to adequately describe the factors influencing the umbrella design to permit the ultimate selection of one or more near-optimum designs on the basis of the mechanical analysis.

The following factors have been extracted from subsection (3) of this section.

(a) All other factors remaining the same, the increase in ηXBW for increase in antenna height (scale factor), h_T, to new height h_T^1 is $(h_T^1/h_T)^3$ times the ηXBW.

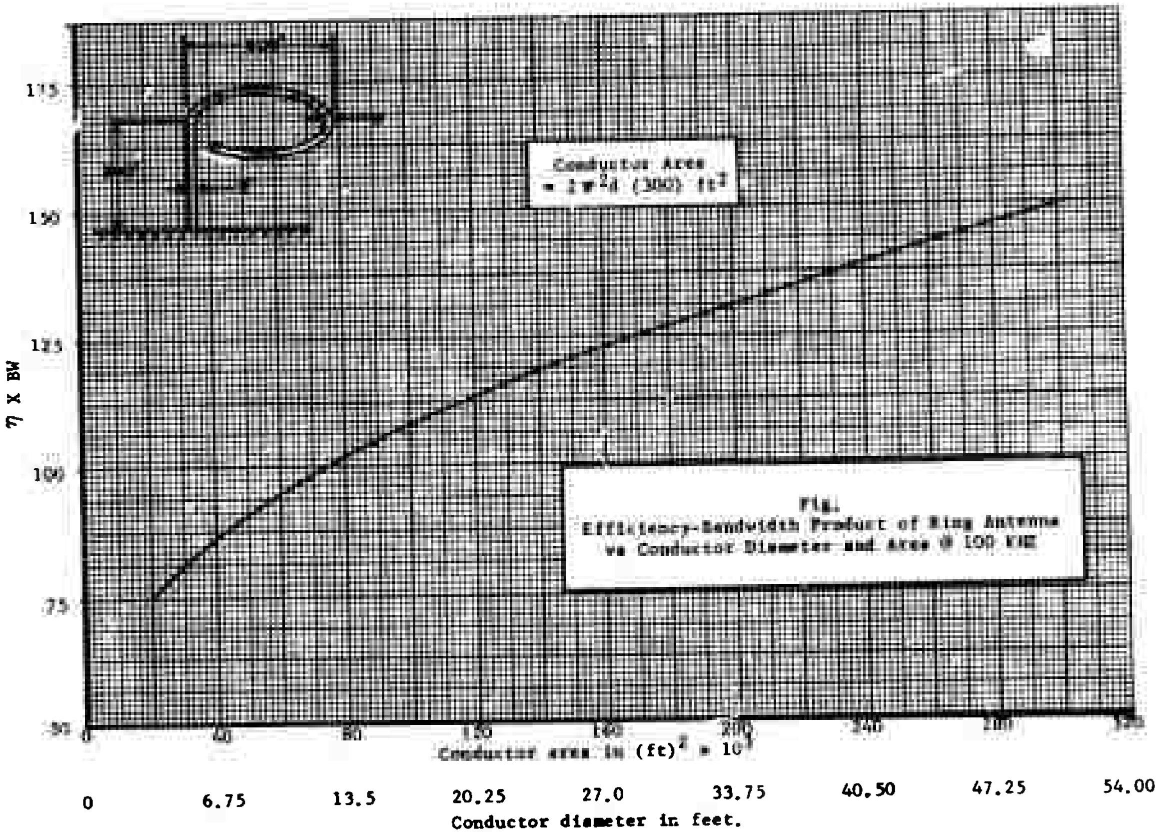


Figure 21. Efficiency-Bandwidth Product of Ring Antenna vs. Conductor Diameter and Area @ 100 KHz

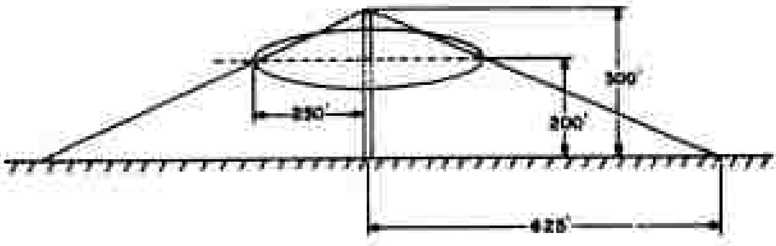


Figure 22. Single Tower Geometry to Support 250 Foot Disc

(b) The ηXBW is increased when the number of umbrella wires is increased. For an umbrella with optimum $1/h_T$ and angle θ_T of the order of 45-50 degrees increase from 6 to 9 wires give 24 percent ηXBW increase, increase from 9 to 12 wires give 16 percent ηXBW increase, increase from 12 to 24 wires give 20 percent ηXBW increase, increase from 9 to 24 wires give 38.6 percent ηXBW increase.

(c) An increase in allowable land area will give an increase in ηXBW. For the conditions of (b) above and 12 wires, an increase in land area required by an increase in tower height gives: 10 percent increase in tower height increases the land area required by 33 percent and increases the ηXBW by 33 percent when the initial ηXBW is about 100.

(d) For umbrella cone angles which are reasonable for Loran-D (40-50 degrees) the umbrella wire length is approximately equal to the tower height for maximum ηXBW.

(e) All other factors remaining the same, the increase in ηXBW for increase in frequency f_1 to new frequency f_2 is $(f_2/f_1)^4$ times the ηXBW.

3. EMPIRICAL TECHNIQUE

a. GENERAL

The major problem in the empirical determination of ηXBW is in obtaining efficiency. The measurement of bandwidth for electrically small antennas under matched input conditions is a function of the reactance and the slope of the reactance curve at the frequency of interest. The measurement of reactance is usually quite accurate. To obtain the antenna efficiency, it is necessary to measure the gain. Two techniques are more prominent than others for this measurement.

One technique involves transmitting from an antenna of calculable power input and gain, receiving a signal at the test antenna which can be referred to an open circuit voltage at the test antenna terminals, and comparing this voltage to one obtained by transferring the known radiated power from the transmitting antenna to a received voltage at the test antenna assuming 100 percent efficiency.

The second technique involves measuring the absolute incident field strength from an arbitrary transmitting antenna which is placed so as to illuminate the test antenna with a vertically polarized plane wave front. The received voltage at

the test antenna is also measured, as in the first technique, and this voltage is compared to that calculated from the known incident field strength and a perfect test antenna. The assumption made in each of these techniques is that the test antenna radiation pattern does not change when the test antenna is no longer perfect. This assumption is probably quite valid if the transmitting and test antennas are both mounted on a large ground screen.

The latter technique was used in this program because, if means are available to measure the field strength accurately, the gain measurement is not as much a function of the quality of the ground screen installation and the transmitting antenna. The incident field strengtn can be measured either by using a device available for this purpose such as Empire Device's NF-105 signal strength meter, or by using an electrically, very short vertical whip, and measuring the received voltage unit. In the latter case, the received voltage is transformed to an open circuit voltage, and the additional terminal zone shunt capacitance is mathematically removed.

b. MEASUREMENT ηXBW EQUATION DERIVATION

The voltage measured, V_m, of the test antenna is related to the open circuit voltage, V_{oc}, by the Thevenin's equivalent circuit shown as figure 23. For the case at hand, the load reactance, X_T, equals zero and the load resistance, R_T, equals 50 ohms. The received power, W_R, is given by[13]

$$W_R = \frac{E_{inc}^2 (\theta_o, \phi_o)\, A\, (\theta_o, \phi_o)}{120\,\pi}$$

where E_{inc} (θ_o, ϕ_o) is the incident field strength impinging in the desired direction, A (θ_o, ϕ_o) is the antenna aperture in that direction. From the equivalent circuit with $X_T = 0$ and $R_T = 50$ ohms

$$\frac{V_m^2}{50} = \frac{V_{oc}^2\, 50}{(R_a + 50)^2 + (X_a + X_T)^2}$$

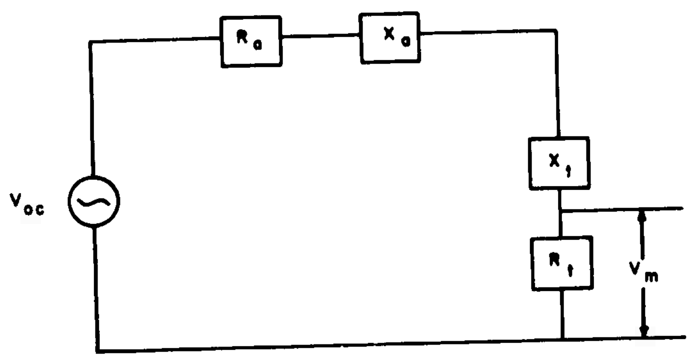


Figure 23. Thevenin's Equivalent Circuit Representation of Test Antenna

and the antenna aperture is given by

$$A = 120\pi \frac{V_{oc}^2}{E_{inc}^2} \frac{1}{\left(\frac{R_a}{50}+1\right)^2 + \left(\frac{X_a}{50}\right)^2} = \frac{120\,\pi\, V^2_{\;m}}{50\, E_{inc}^2}$$

For electrically small antennas, $\frac{R_a}{50} \ll 1$ and

$$A = \frac{120\,\pi}{50} \frac{V_{oc}^2}{E_{inc}^2} \frac{1}{1+\left(\frac{X_a}{50}\right)^2}.$$

If the test antenna is matched, the

$$A_{TAM} = \frac{120\,\pi\, V_{oc}^2}{4\, R_a} = \frac{120\,\pi\, V_m^{\;2}}{4\, R_a}\; 1 + \left(\frac{X_a}{50}\right)^2$$

and since

$$\eta = \frac{A_{TAM}}{A_{PMM}}$$

where A_{PMM} is the aperture of a perfect short matched monopole = $0.06\,\lambda^2$.

The efficiency is then given by

$$= 1.75 \times 10^{-2} f_{mc} \left(\frac{V_m}{E_{inc}}\right)^2 \frac{1}{R_a} \left[1 + \left(\frac{X_a}{50}\right)^2\right]$$

where f_{mc} is the frequency in MHz.

From section IIA

$$BW = \frac{f\, R_a}{Z_o}$$

where

$$Z_o = \frac{f_o \left(\frac{d\, X_a}{df}\right)\Big|_{f_o} + X_a}{2}$$

so that

$$\eta XBW = 1.75 \times 10^4 \frac{f^2_{mc}}{Z_o} \left(\frac{V_m}{E_{inc}}\right)^2 \left[1 + \left(\frac{X_a}{50}\right)^2\right].$$

This latter equation was used in calculating the ηXBW for all the model measurements. The formula demonstrates the value of ηXBW as a figure of merit for electrically small antennas in that the measurement of radiation resistance or loss resistance need not be made.

c. DESCRIPTION OF MEASUREMENTS

The test procedure for determining efficiency bandwidth was done in the following steps.

(1) Field strength measurement. Using the Empire Device's NF-105 with its calibrated loop antenna and 30-foot RG58U coax the incident field was measured at the ground plane center disc with a fixed input at the remote transmit antenna.

(2) The loop antenna was then replaced by the 2-meter whip. While maintaining the transmitted level, a reading was made on the E.D. NF105 meter. The coax was then removed from the base connector of the standard whip antenna and attached to the output jack of the signal generator. The signal generator level was then set to where the E.D. NF105 reading was repeated. The signal generator level was then read and this reading was taken to be a standard field strength level to be compared to the field strength level of step one above.

(3) Daily measurements were made with the standard whip during the course of the study and any deviation from the original standard whip measurement in step (2) was used to calculate the change in incident field strength by direct proportional calculation.

(4) Similar to the step (2) method of received voltage measurement, the received voltage level at the terminals of the model under study was determined by a substitution method. The same level of signal was fed to the remote transmit antenna as was used for determining field strength and received on the model under study. The gain setting of the E.D. NF105 was set to some meter reading. The coax was then removed from the terminals of the model under study and connected to the output jack of the signal generator. The generator level was then set to produce the same meter deflection on the E.D. NF105 and the generator output level recorded as the received voltage of the model under study.

(5) Impedances were measured at three frequencies for bandwidth determination. Ten megahertz was determined to be the test frequency to correspond to the 100 to 1 scaling factor of the models studied. Additional points, one above and one below 10 mc, were measured. Impedances were measured using the General Radio 1606 bridge. To minimize attenuation and rotation of the impedances measured, the bridge was located immediately under the ground screen and connected to

the model under study with a 10 inch piece of RG58U coax. Attenuation could then be neglected but rotation of the impedances read at the bridge were necessarily rotated to the antenna terminals. Rf voltage measurements were made through common pieces of coax to eliminate attenuation errors.

The efficiency bandwidth product of the models tested was calculated using the following methods:

(1) Impedances measured were rotated through a 10-inch length of coax used to connect the model to the impedance bridge. This corrected the impedances read at the bridge to the impedances that appeared at the antenna terminals. To accomplish this formula

$$Z\ in = Z_o \frac{Z_r + j\, Z_o \tan \beta \ell}{Z_o + j\, Z_r \tan \beta \ell}$$

where

$Z\ in$ = impedance read at bridge

Z_o = 50 ohm line impedance

Z_r = impedance rotated through transmission line

$\tan \beta \ell$ = tan of electrical angle of rotation

was rearranged to determine the unknown, Z_r. $\tan \beta \ell$ was determined by short readings taken on the line through which the impedances are to be rotated.

$$\tan \beta \ell = \frac{X_{sc}}{Z_o}$$

where X_{sc} = short circuit reactance reading.

(2) Base capacity of the model was eliminated from the antenna reactance readings by first measuring the base structure (less elements and mast) of the model for distributed capacity. This capacity was then removed by: $X_A = X_t - X_B$

$$X_t = \frac{Z_a X_b}{X_a + X_b}$$

from which:

$$Z_a = \frac{R_a X_b X_a + R_a X_b (X_b - X_a) + jX_a X_b (X_b - X_a) - jR_a^2 X_b}{R_a^2 - (X_b - X_a)^2}$$

where

Z_a = antenna impedance

R_a = antenna resistive component

X_a = antenna reactive component

X_b = base capacitance

(3) The Q of the antenna is calculated by:

$$Q = \frac{f_o (\Delta X_a) + X_a}{2R_a}$$

where

f_o = operating frequency at band center

ΔX_a = reactance of lowest frequency less reactance of highest frequency measured

(4) The bandwidth was determined by:

$$F = \frac{f_o}{Q \text{ (scale factor)}}$$

(5) Efficiency was determined by:

$$\eta = 1.78 F_o \left[\left(\frac{V_m}{E_{inc}}\right)\right]^2 \left(\frac{1}{R_a}\right) \left[\left(\frac{R_a}{Z_o} + 1\right)^2 + \left(\frac{X_a}{Z_o}\right)^2\right]$$

where

V_m = voltage measured at antenna terminals

E_{inc} = incident field strength

(6) Efficiency bandwidth product was determined by obtaining the product of steps (4) and (5) above.

d. DESCRIPTION OF TEST FACILITY

The test facility of the Loran-D study was composed basically, of a ground plane, the housing for test equipment located at the ground plane center, the test equipment, and the associated test antennas used for the antenna model study.

The ground plane was constructed with a 12-foot circular copper-covered disc as the center from which 90 soft drawn copper wires radiated at 4 degree increments to a diameter of 200 feet. Extensions of a 45 degree wedge to a diameter of 400 feet provided a ground plane surface complete between the plane center and a remote transmitting antenna. The ends of the wires contained in the 45 degree wedge were tied together with an additional wire. Figure 24 is a diagram of the test plane.

Located under the 12-foot disc at the ground plane center, a 6-foot diameter silo served as the testing facility for housing the test equipment and personnel. The test equipment included an impedance bridging setup, a field strength measurement setup and three test antennas not including the the models studied. The impedances were determined using a Hewlett-Packard 606A signal generator, a General Radio 1606 impedance bridge and an Empire Devices NF105 field strength meter used here as a null detecting receiver. See figure 26. Field strength measurements were made using the same Empire Devices NF105 and its calibrated LP105 loop antenna and coaxial cable. A 2-meter whip antenna was constructed for a reference receive

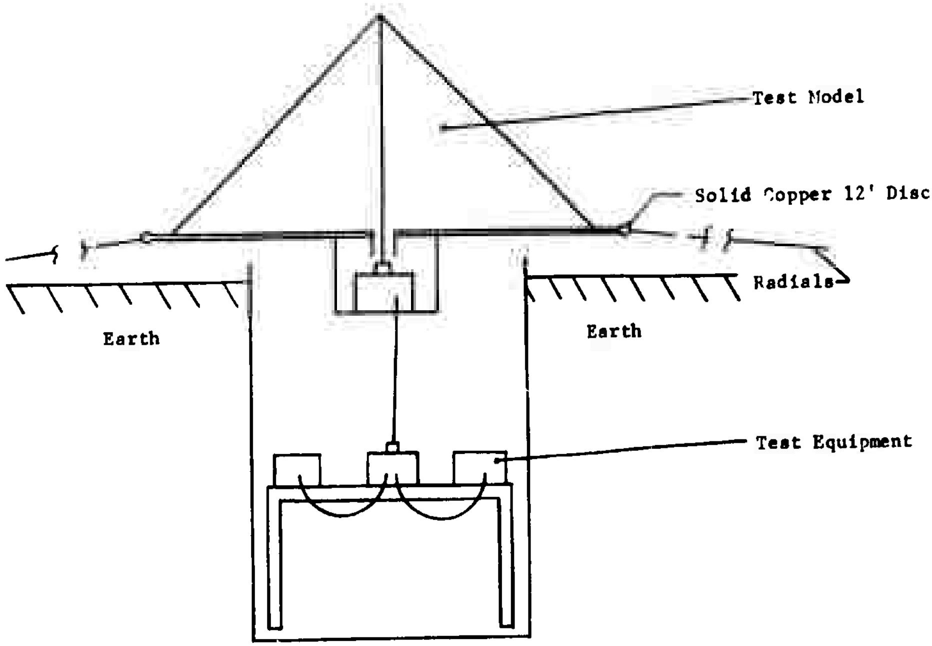


Figure 24. Test Facility

antenna and a cage monopole was constructed to serve as our remote transmitting antenna with an underground coaxial cable run back to the underground test silo. This remote transmitting antenna was located at the center of the 45 degree wedge and at the perimeter of the wedge as shown in figure 25.

4. FULL-SCALE CONSIDERATIONS

a. POWER LIMITATIONS

As the electrical height of the Loran-D antennas is small compared to a quarter-wavelength antenna, the peak voltage appearing at any point on the structure will be only slightly larger than the peak input voltage. To obtain an estimate of the voltage increase to be expected, consider the equivalent circuit of figure 30. The capacitance, represented by reactance X_L, is the load reactance of the umbrella wires. The inductance, represented by reactance X_m, is that caused by the mast. This inductance (ref. "impedance concept" umbrella calculations of III 2 a 2 may be considered as two parts; that of the "unmasked" portion of the tower as a transmission line, and that of the coaxial shorted section represented by the "masked" portion of the mast placed coaxially inside of the top inverted cone formed by the umbrella wires. The

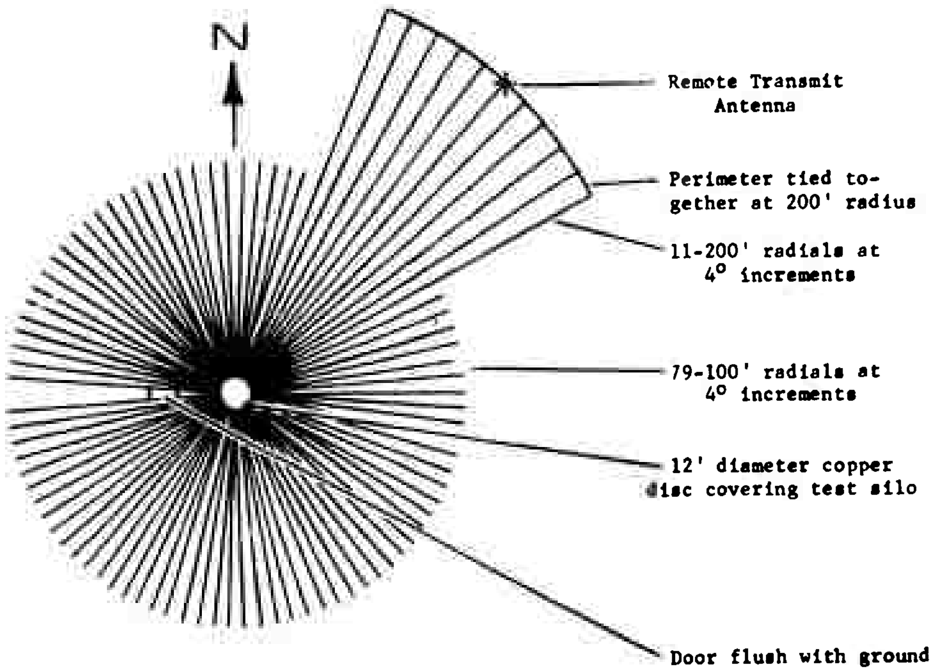


Figure 25. Ground Plane

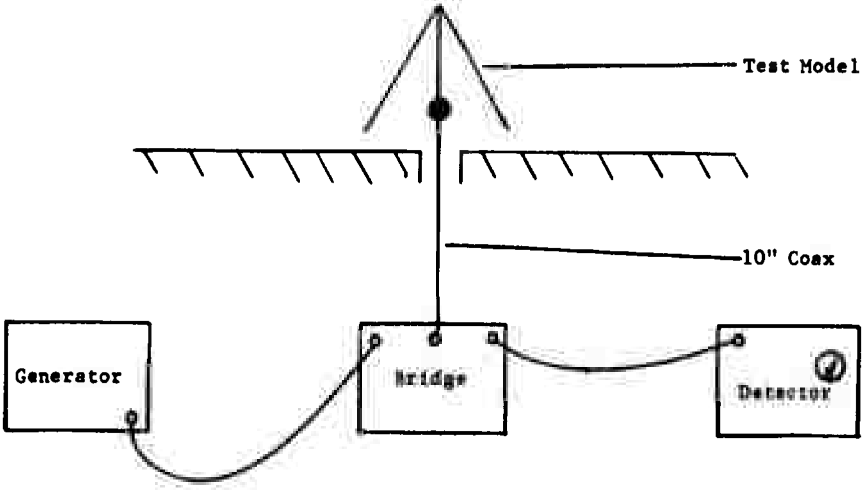


Figure 26. Impedance Measurement Setup

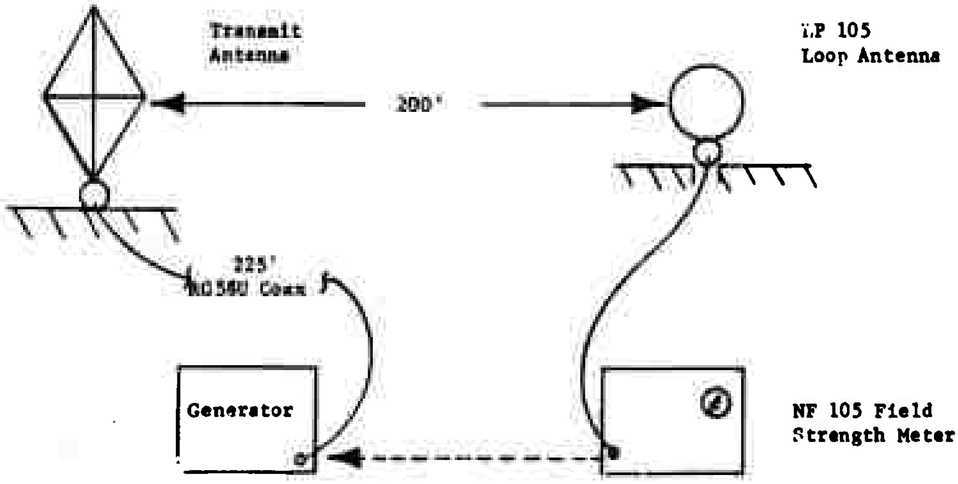


Figure 27. Incident Field Strength Measurement

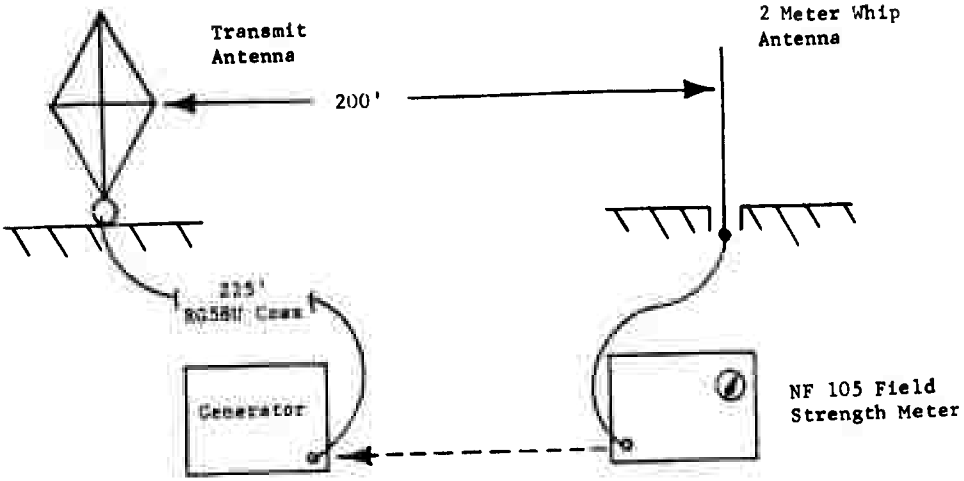


Figure 28. Standard Whip Voltage Measurement

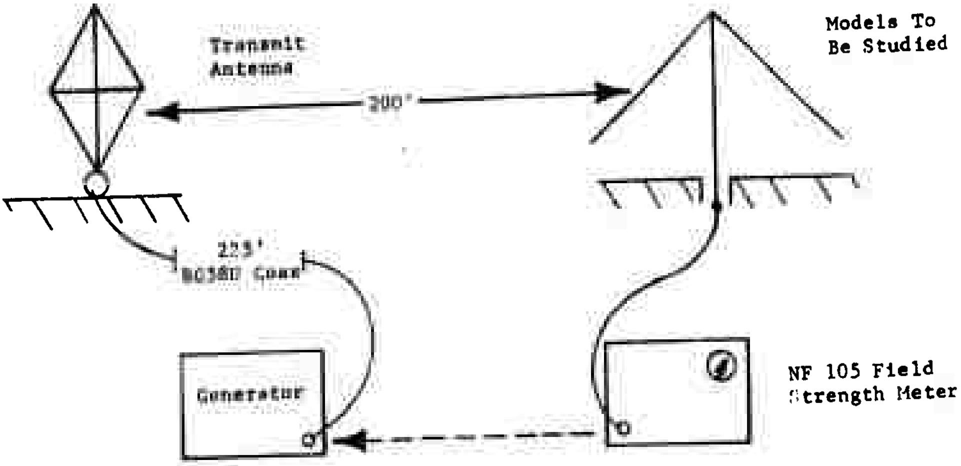


Figure 29. Model Antenna Voltage Measurement

$$V_{max} = \frac{X_l}{X_l - X_m} \; V_{in}$$

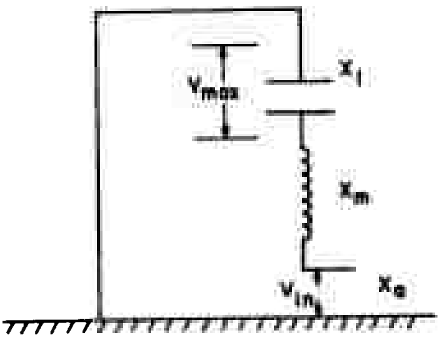


Figure 30. Equivalent Circuit of Umbrella Antenna for Estimating Maximum Voltage

input reactance is X_a. The maximum voltage on the structure is then given approximately by

$$V_{max} \quad \frac{X_L \, V_{in}}{X_a} = \frac{X_L}{X_L - X_m} \quad V_{in} \; ,$$

where the peak input voltage has previously been defined as 50 kv. Calculations for the 49 degree 12 wire umbrella give X_L and X_a equal to 464.5 and 385 ohms respectively. The "voltage increase factor" is the 1.2; thus the maximum peak voltage on the structure is about 60 kv.

From a voltage breakdown standpoint, there are three major considerations. These are:

(1) The maximum voltage which can exist on the elevated wires before voltage breakdown (corona and spark-over) occurs.

(2) The maximum voltage which can exist on the terminations (ends and joints) of the elevated wires before voltage breakdown occurs.

(3) The size at the base insulator required to prevent voltage breakdown due to the peak input voltage.

The mast or tower is large enough in diameter that the voltage between it and ground will not produce a voltage breakdown condition.

An estimate of the voltage breakdown condition of the elevated wires may be made by considering the maximum voltage on a wire parallel to the ground and at

the minimum height of the elevated wires. For an open-circuited parallel wire above perfect ground, the maximum voltage is given as[14]

$$V_m = 21.5 \left(1 + \frac{.202}{\sqrt{p}}\right) \left[2p \ln \frac{2h_w}{p}\right], \quad h \gg p$$

where V_m is in kilovolts under standard conditions (30 in Hg at 23 degrees centigrade)

p is wire radius in inches

h_w is height of wire in inches

Consider a 250-foot umbrella with a 49-degree angle and wire length equal to the height. The minimum wire height above ground is 86 feet. If the wire diameter is taken as 3/16 inches. Then V_m = 308 kv; thus the first consideration presents no problem.

The second case is involved with the minimum radius of curvature which small protruding parts elevated above ground at the minimum wire height may be such that 70 kv will not produce voltage breakdown. This may be estimated by considering the maximum voltage which can be applied to a sphere at a given height above ground. For a sphere with height much greater than the sphere radius, this voltage is independent of height and is given by [15]

$$V_m = 54.5\, p \left(1 + \frac{0.54}{\sqrt{p}}\right), \quad h \gg p_r$$

where V_m is in kilovolts under same conditions as before

p_r is sphere radius in centimeters.

For a V_m of 70 kv, the minimum radius is 0.66 cm. This radius at curvature does not apply to parts which are more cylindrical than spherical and which are not isolated (protruding like a bolt, etc.). There will be no problems evolving from this second consideration.

The base insulator criteria are easy to estimate in that the voltage is a known value, and the insulator is located at a fixed height; but the criteria is also difficult in the sense that temperature, humidity, and contamination of the insulator material greatly affect the allowable voltage. For ordinary fluted insulators in dry air, the minimum height for about 18 cm diameter and 50 kv is about 20 cm, for air densities as low as 0.5. Similarly, and for the same conditions, a 30-cm high fluted insulator can stand 75 kv. The best type of insulator is one with one or more corona caps on it. These insulators are alternately called suspension insulators or shaped insulators. Such an insulator is shown pictorially in figure 31. The effect of the cap is to relieve the electrical stress on the dielectric portion of the insulator. Collins Radio Company has built insulators of this type whereby the cap or caps are shaped to correspond to an equipotential surface. This design places minimum electrical stress (voltage gradient) across the insulator surface. Peek[16] shows that a single 30-cm diameter cap with an insulator spacing of 16.5 cm for an air density at 0.5 cm can withstand 60 kv. For an air density of 1.0 this insulator can withstand 72 kv. The difficulty establishing base insulator requirements should not be underestimated. For example, saline environments can appreciably lower the corona and flash over voltage levels. Also,

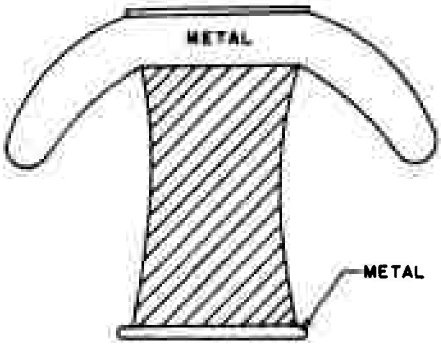


Figure 31. Pictorial Representation of Shaped Insulator

because the 50 kv will be applied instantaneously, the problems of weird transient effects and surface anomalies causing premature breakdown become much greater.

b. INSULATOR DESIGN

As the base insulator is likely the most critical electrical component of the antenna, some analytical comments are due as well as comments on commercially available insulators and insulating materials. The rise time of the electrical pulse has been given as about 80 microseconds. This means that the maximum significant frequency components of the pulse are of the order of 100 KHz. This factor is important in evaluating the dielectric loss to be expected due to the insulator. Known requirements for this base insulator are:

(1) Mechanical compressional load of greater than 40,000 pounds

(2) Voltage breakdown (flashover point) greater than 100 kv (safety factor of 2 or greater) when wet

(3) Minimum insulator capacitance

A typical commercial insulator to meet these requirements is the LOCKE[17] type 25048. This insulator is 30-inches high (dielectric portion) 22 1/2-inches wide at the top tapering down to about half that at the base. The recommended working load is 100,000 pounds, the quoted wet flashover point is 105 kv, the capacity of the dielectric is about 2 pf and it is made of porcelain. The loss tangent of porcelain at 100 KHz is about 0.01 and the relative dielectric constant is about 5.3. The effect of an insulator must be considered from an impedance point of view as well as from voltage breakdown and structural considerations. This effect may be estimated by considering the equivalent circuit at figure 32. In this circuit

R_i is the shunt dielectric loss resistance

X_i is the shunt capacitance of insulation

X_{ei} is the shunt terminal zone capacitance external to the dielectric

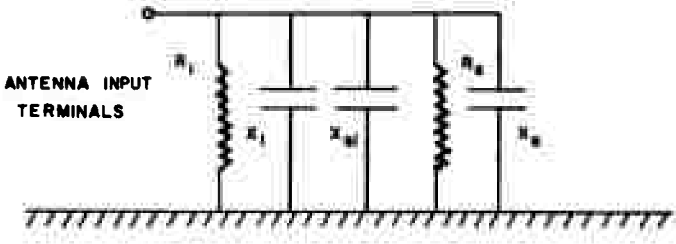


Figure 32. Equivalent Circuit for Analysis of Base Insulator

R_{pa} is the shunt or parallel equivalent input resistance

X_a is the antenna input capacitance

Now, $R_{pa} = Q^2_a\, R_a$, where $Q_a = \frac{X_a}{R_a}$ and R_a is the input resistance

similarly $Y_i = \frac{1}{R_i} + j\,\frac{1}{X_i}$

$$= \frac{\sigma}{\epsilon_r\, \epsilon_o}\, C_i + j\, \omega\, C_i$$

$$= \tan\, \delta\omega\; C_i + j\; \omega\; C_i$$

where σ is the insulator conductivity

ϵ_r is the relative dielectric constant

ϵ_o is the dielectric constant at air

$\tan\, \delta$ is the loss tangent equal to the dissipation factor

C_i is the insulator capacitance

For the insulator specified above and for nominal umbrella input impedance

$R_a \approx 0.5$ ohm

$X_a \approx -j\, 400$ ohm

$C_i \approx 2$ pf

$\tan\, \delta \approx 0.01.$

R_{pa} is then $\left(\frac{400}{0.5}\right)^2 0.5 = 32\text{x}10^4$ ohms

$$R_i \text{ is } \frac{1}{0.01\,(2\pi)\ 10^5 \times 2\text{x}10^{12}} = 80\text{x}10^6 \text{ ohms}$$

$$X_i \text{ is } \frac{1}{(2\pi)\ 10^5\ 2\text{x}10^{-12}} = 80 \times 10^8 \text{ ohms}$$

as the efficiency of the equivalent circuit is

$$\eta_e = \frac{R_i}{R_{pa} + R_a} ,$$

and the reactance is so high, the above insulator will not degrade the antenna performance (the capacitance C_{ei} is presumed to be at the order of C_i, which is reasonable. If the insulator were fatter, the C_i would increase (as increase in insulator cross-sectional area) meaning that a greater portion of the "terminal zone" fields are contained within the dielectric. For the above insulator if the top diameters were increased to 38 inches from 22 1/2 inches, C_i increases from about 2 pf to 6 pf (this increase is not required for this insulator, but may be required for other insulators made of different material but with about the same dielectric constant and height). The R_i then drops to $26.7\text{x}10^6$ ohms, which is still acceptable. Suppose, now, that the loss tangent increases to 0.07, which is typical of good phenolic resins. Then R_i for the larger diameter reduces to $38\text{x}10^5$ ohms, which is still acceptable.

The conclusion is that for the particular input impedance parameters, at Loran-D umbrella antennas, the dielectric loss consideration is probably insignificant. Caution must be used in selecting insulators made of fiberglass due to the water absorption properties. The particular insulator chosen for analysis represents typically the characteristics required for this application.

The current carrying capacity of the umbrella wires is expected to be an insignificant consideration in power handling capability since for 50 kv at the antenna input terminals (current of 125 amperes) the peak pulse current in each of the umbrella wires will be less than 10 amperes with 3/16 to 1/4 inch diameter wires being typical.

Particular attention is required at the termination of the radial element wires. An exponential horn shaped corona shield should be attached at this point to minimize rf heating of the fiberglass insulator at the juncture of the insulating material and the conductive radiator.

c. GROUND SCREEEN REQUIREMENTS

The increase in input impedance due to a ground screen consisting of a finite number of wires of finite length has been considered by Wait, [18] Maley and King, [19] Brown and Lewis and Epstein[20] and others. Generally speaking, it is not correct to consider this change of impedance as a change with respect to that over perfect ground, because the current distribution on the radiating portion of the antenna is generally not the same as that found when perfect ground is used. This change, as a change over perfect ground, is valid for capacitively loaded vertical antennas, however, because the current distribution cannot change to any great extent. The problem is, in this case, to determine the effective height properly. The above references show that the change in reactance is only a small percentage of that over perfect ground, thus it cannot have a significant effect on the antenna performance. The change in resistance,

however, is at least as great as the radiation resistance, and thus its consideration is important from standpoints of efficiency and impedance stability.

To estimate the change in resistance, a computer program was written following the method of Wait referenced above and the change in resistance was computed for conductivity's, σ, of 0.01 and 0.001 mho/meter representing average and poor ground conditions respectively. These changes in resistance were computed also for a varying number of radials ranging between 4 and 100, and lengths between 150 and 600 feet. The effective height was chosen to be 0.018 λ, consistent with the 300-foot umbrella nominal values. The data is presented in figure 33. Several interesting results may be observed from examination of this figure. They are:

(1) An increase in the number of radials beyond 40 results in less than a 20 percent decrease in resistance for average ground and less than a 10 percent decrease for poor ground.

(2) If the number of radials is at the order of 10, the length (within limits of 150-600 feet) is relatively unimportant.

(3) Any increase in radial length beyond the 200-feet radius is relatively unimportant.

Perhaps the most reasonable design goal for ground resistance is to try and keep it less than 10 percent of the total input resistance. This is important from two aspects. The first is that climatic and environmental changes can cause a considerable fluctuation at this resistance. If the fluctuations are significant, they will produce instability of the input resistance causing a corresponding fluctuation in antenna efficiency and bandwidth, which also complicates impedance matching. The second is that of obtaining a positive control of efficiency. That is, it is probably most desirable to be able to lower the efficiency at will by adding series resistance to the antenna, than trying to provide the desired level of efficiency by designing-in inherent antenna system loss. From all of the above considerations and the curves of figure 33, the logical choice is about 40 radials of 300 feet in length.

The umbrella is, of course, an extended structure. That is, it is broad in terms of land area. This factor will probably change the effect of the assumed length of the radials slightly, but should not change the effect of the number of radials. Also, it should be possible to design the screen with radials at varying length. It is quite possible that the length of the radials not directly underneath the respective umbrella wires could be shorter than those directly underneath.

Because of the low frequency, the manner in which the radials are laid out (buried and grounding point effects) should not make much difference. Certainly, these effects cannot be counted on for improvement in a design where the antenna must be installed in a variety of locations with different soil conditions.

The size of the wire used is probably most important in terms of the ohmic loss involved, as the number of radials used (at about 40), using wire sizes varying from #6 to #12 copper weld, will handle the current. If #6 wire is used the resistance is about 1 ohm/1000 feet or 0.33 ohms per 300 feet. For 40 radials, the ohmic loss resistance of the wires at the antenna terminals assuming uniform current would be about 0.008 ohms. Correspondingly for #12 wire, the input resistance would be about 0.045 ohms. Probably about a number 9 or 10 wire (Rin $\approx$ .025 ohms) would be the

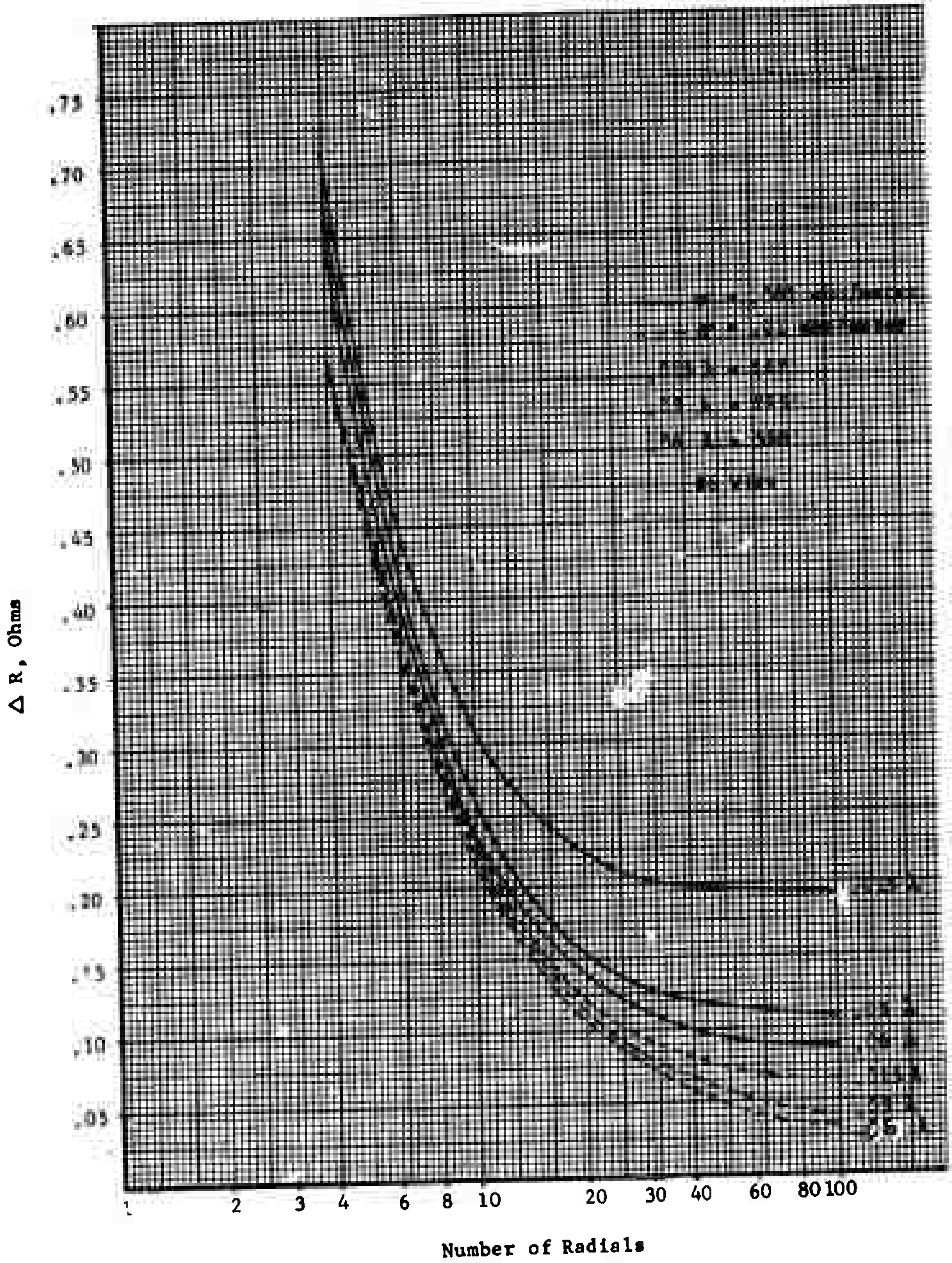


Figure 33. Ground Screen Resistance for Radial Ground Wire System with Effective Height = .018 @ 100 KHz

most reasonable choice, unless the resistance is unimportant because of the designed operating efficiency, in which case a small wire (about #12) would be best.

5. MECHANICAL CONSIDERATIONS

The primary requirements of the Loran-D antenna support structure are high strength-to-weight ratio, ease of assembly and disassembly, simplicity, ruggedness and personnel safety. Many types of structures are available or being developed which could satisfy the antenna system requirements to varying degrees. System trade-offs, taking into consideration the desirable and undesirable characteristics of the various types, were all used to aid in the selection of the recommended structure.

The major problem areas applying to a lightweight tactical antenna support structure are discussed in the following paragraphs:

a. SUPPORT STRUCTURE

(1) Stress Analysis

An analysis of guyed towers involves the solution of a multiple redundant beam-column on spring supports further complicated by the catenary action of the guys. The solution is so complex that a hand solution would require a great number of simplifying assumptions reducing the accuracy considerably.

By using a digital computer program we cannot only avoid these inaccuracies but perform the analysis with much greater speed. This increased speed also allows the solution of a much greater number of cases.

Figure 34 shows a flow diagram of the computer program with the following pages describing the various steps.

(a) <u>Input Data</u>

The inputs which must be supplied to the computer program for each solution are listed below.

Wind Velocity

Temperature Differential

Ice Accumulation on Tower

Ice Accumulation on Guys

No. of Guys at each Guy Location

Height of each Guy tied to Tower

Stiffness (AE) of each Guy

Coefficient of Thermal Expansion of each Guy

Preload Tension for each Guy

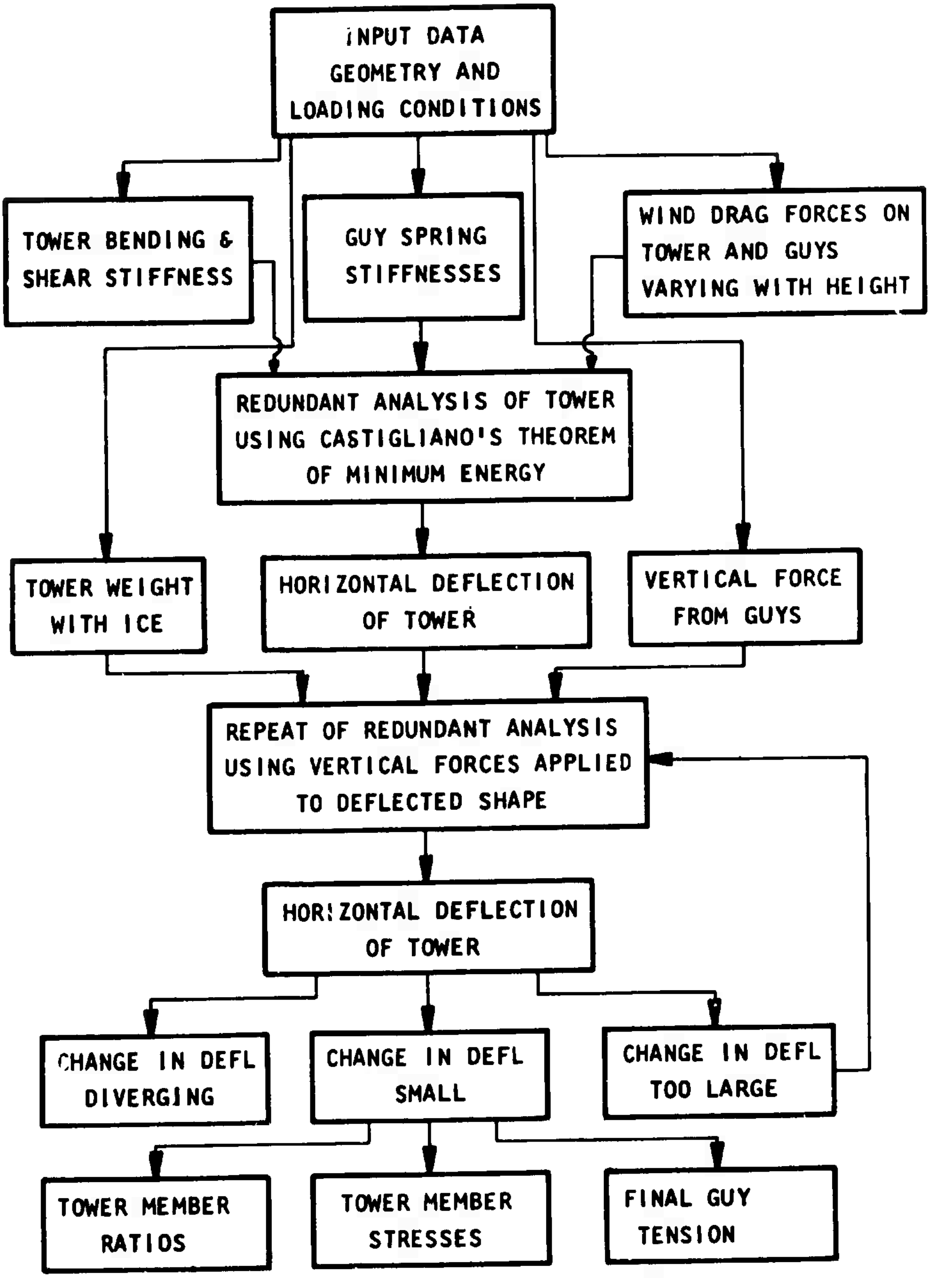


Figure 34. Computer Program Flow Diagram

Weight of each Guy

Diameter of each Guy

Distance from Tower Base to Ground Anchor of each Guy

Tower Configuration

Tower Material, Modulus of Elasticity, Coefficient of Thermal Expansion, and Density

Diameter and Wall Thickness of Legs, Diagonals, and Horizontals

Diameter, Weight per Foot and Length/Height Ratio for non-structural Member

(b) Tower Bending & Shear Stiffness

The section properties of the tower are computed from the input data for the tower. For example, the bending stiffness (IE) is computed by the formula for a triangular tower

$$IE = \frac{\pi}{2} t_{W_L} \left(D_L - t_{W_L}\right) d^2 E \quad \text{(Refer to Appendix III)}$$

where I = moment of inertia in in.^{4}

E = modulus of elasticity in lb/in.^{2}

t_{W_L} = wall thickness of leg in in.

D_L = diameter of leg in in.

d_1 = distance between legs in in.

The shear stiffness is expressed as (AG) corresponding to a beam web stiffness. For a triangular X-brace configuration, the equation is:

$$AG = \frac{\pi h E}{\dfrac{\left(d_1^2 + h^2\right)^{1.5}}{1.5\, d_1^2\, t_{W_D} \left(D_D - t_{W_D}\right)} + \dfrac{.577\, d_1}{t_{W_H} \left(D_H - t_{W_H}\right)}} \quad \text{(Refer to Appendix III)}$$

where h = vertical height of diagonal in inches

t_{W_D} = wall thickness of diagonal in inches

D_D = diameter of diagonal in inches

t_{W_H} = wall thickness of horizontal in inches

D_H = diameter of horizontal in inches

other configurations are computed similarly.

(c) Guy Spring Stiffness

The tower redundant analysis assumes the guys act as horizontal springs resisting the side motion of the tower. The guy spring stiffness is computed by the following formula until the preload is relieved in the leeward guys.

$$K = \frac{\eta \; AE \; S^2}{2 \; (l^2 + S^2)^{1.5}} \qquad \text{(Refer to Appendix III)}$$

where K = spring rate in lb/ft

η = number of symmetrically located guys

AE = stiffness of guy wires

S = distance from base of tower to guy ground anchor in ft.

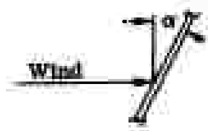
l = height from ground to guy tie to tower in. ft.

When the preload is relieved in the leeward guy, the spring rate drops 50%.

(d) Wind Forces on Tower and Guys

The wind drag on the tower assumes that each member is exposed to the wind with no influence from the other members. The wind force on a member is found by the formula

$$W = .000212 \; C_D \; V^2 \; (D + 2t_{ice}) \cos^3 \alpha$$



where W = wind loading in lb/ft

C_D = drag coefficient f(member size, shape, wind v, temperature, and density) ≈ 1.73 for small round members

V = wind velocity at altitude in mph

D = diameter of member (in)

t_{ice} = thickness of ice on member (in)

α = angle of incidence of member to wind direction

The wind velocity is varied with altitude as shown in figure 35 for coastal areas.

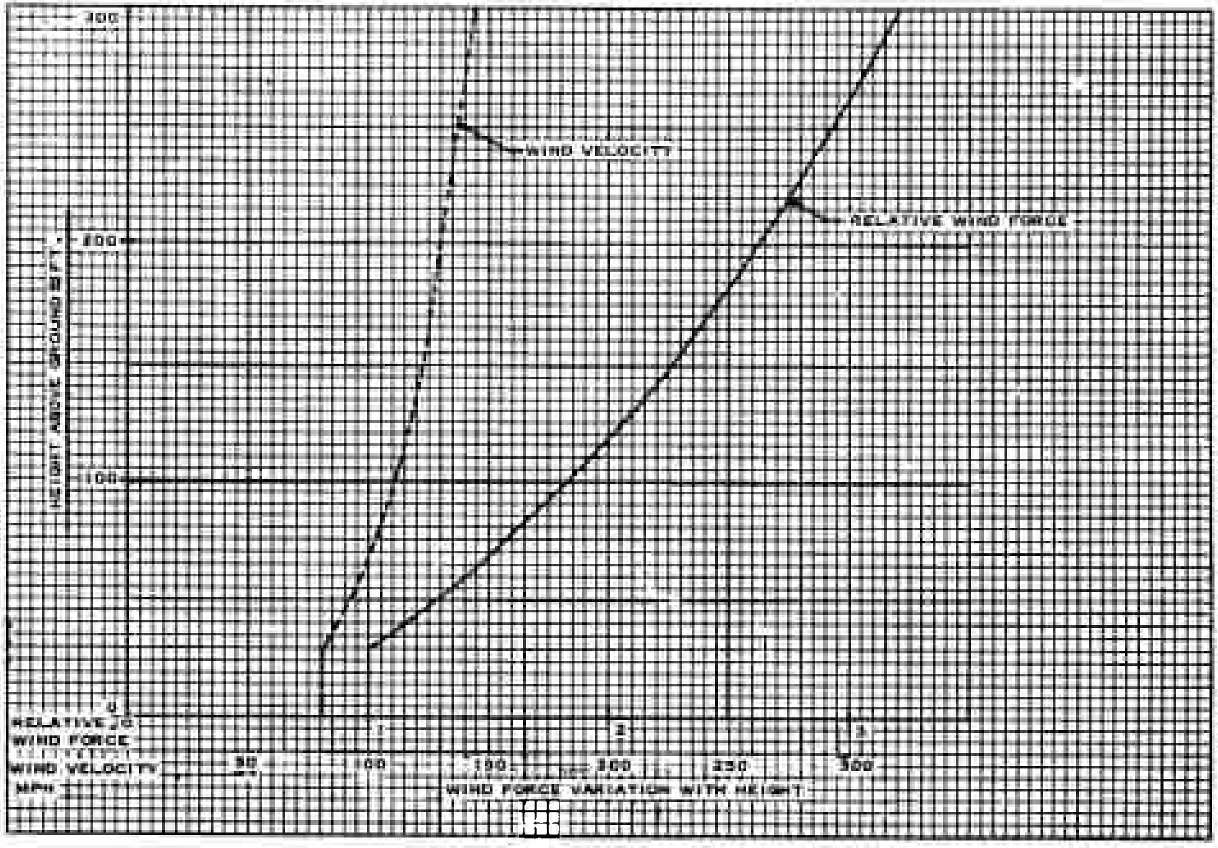


Figure 35. Wind Force Variation with Height

(e) Redundant Analysis of Tower

The general guyed tower represents a redundant mechanical system which nature solves by minimizing the total energy stored in the system in springs of the guys, and bending, and shear of the tower sections. There are of course the restraints that the external moments and shear be zero if the tower is to stand in one place.

The energy equation is (refer to figure 36 for definition of variables)

$$U = \sum_{i=1}^{M} \left(\frac{m_i^{\,2}\, \Delta l_i}{2\, EI_i} + \frac{v_i^{\,2}\, \Delta l_i}{2\, GA_i} \right) + \sum_{j=1}^{N} \frac{F_j^{\,2}}{K_j}$$

where EI_i and GA_i are the effective bending and shear characteristics respectively of the i^{th} section and K_j is the effective spring rate of the j^{th} guy.

The moment in the i^{th} section is

$$m_i = m_o + f_o l_i + \sum_{j=1}^{i} f_j (l_i - l_j) = \sum_{k=1}^{N} F_k (l_i - L_k) \nabla_{ik}$$

$$\text{n.b.} \qquad \nabla_{ik} \doteq \begin{Bmatrix} 1, \; l_i > L_k \\ 0, \; l_i > L_k \end{Bmatrix}$$

while the shear in the i^{th} section is

$$v_i = f_o + \sum_{j=1}^{i} f_i - \sum_{k=1}^{N} F_k \nabla_{ik}$$

These equations can be reduced to

$$m_i = cm_i - \sum_{j=1}^{N} F_j \nabla_{ij} (l_i - L_j)$$

$$v_i = cv_i - \sum_{j=1}^{N} F_j \nabla_{ij}$$

by combining the known quantities.

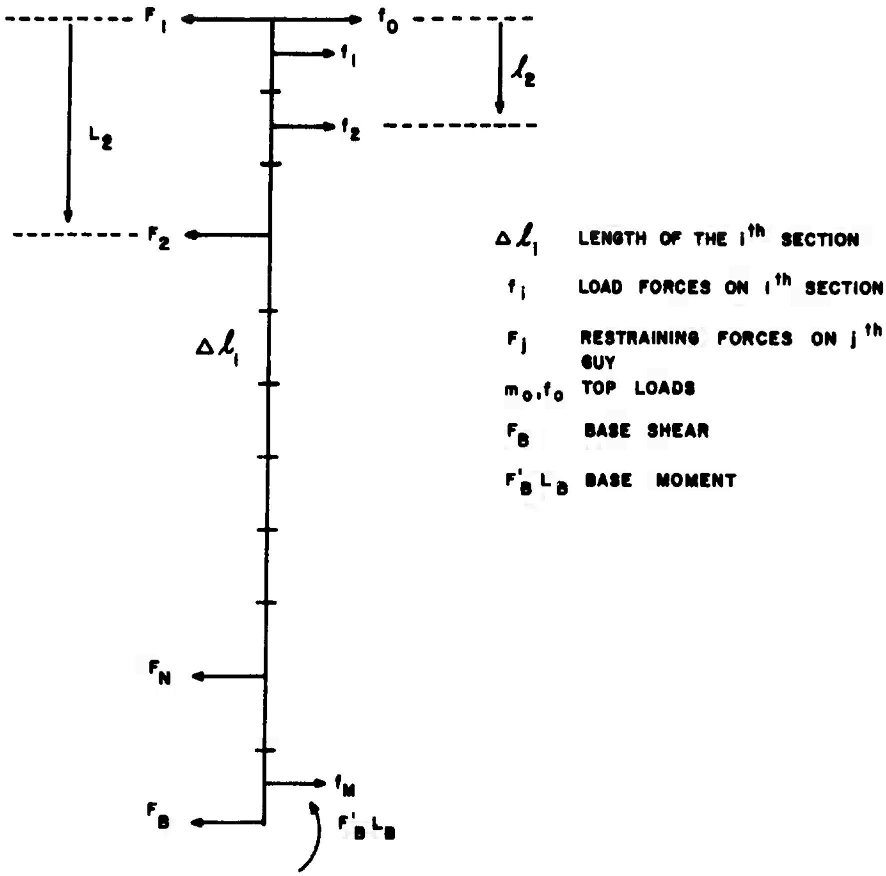


Figure 36. Definition of Variables

The external moment and shear constraint equations are:

$$\phi_1 = \sum_{i=1}^{N} F_i \, (l_M - L_i) + F_B' L_B - c v_M = 0$$

$$\phi_2 = \sum_{i=1}^{N} F_i + F_B - c v_M = 0$$

Minimizing the energy function U subject to the constraints ϕ_1 and ϕ_2 can be shown to be equivalent to minimizing a new function U' defined as

$$U' \doteq U + \lambda_1 \phi_1 + \lambda_2 \phi_2$$

where λ_1 and λ_2 are called Lagrangian multipliers. To minimize U' we set the partial derivatives of U' with respect to F_1, $F_2 \ldots F_N$, F_B, F'_B, λ_1, λ_2 equal to zero.

$$\frac{\partial U'}{\partial F_k} = \sum_{i=1}^{M} - \Delta l_i \nabla_{ik} \left(\frac{Cm_i (l_i - L_k)}{EI_i} + \frac{CU_i}{GA_i} \right) \tag{1}$$

$$+ \sum_{j=1}^{N} F_j \left(\Delta l_i \nabla_{ik} \nabla_{ij} \left(\frac{(l_i - L_k)(l_i - L_j)}{EI_i} + \frac{1}{GA_i} \right) + \frac{S_{jk}}{K_j} \right) + \lambda_1 (l_m - L_k) + \lambda_2 = 0$$

$$\frac{\partial U'}{\partial F_B} = \lambda_2 = 0 \tag{2}$$

$$\frac{\partial U'}{\partial F'_B} = \lambda_1 L_B = 0 \tag{3}$$

$$\frac{\partial U'}{\lambda_1} = \sum_{i=1}^{N} F_i (l_M - L_i) + F'_B L_B - cm_M = 0 \tag{4}$$

$$\frac{\partial U'}{\lambda_2} = \sum_{i=1}^{N} F_i + F_B - cv_M = 0 \tag{5}$$

Equation (2) shows $\lambda_2 = 0$ always and can, therefore, be eliminated in all equations. Equation (3) shows λ_1 to be indeterminant when $L_B = 0$. To correct this problem Equation (3) and F'_B are deleted when $L_B = 0$. The computer solves the remaining equations simultaneously.

(f) Tower Weight with Ice

The weight of the tower is computed by accumulating the computed weight of individual tower members. The ice weight is then added based on the ice forming a tube around the member with the wall thickness corresponding to the ice thickness and the inside diameter at the diameter of the member. The ice is computed at weighing 56 lb/cu ft.

(g) Vertical Force from Gu

The tower will feel a vertically applied load from the guys at the tie point between guy and tower.

First, the preload will exert a downward component to the tower. After the preload has been exceeded in the leeward guys, the windward guys will exert a downward force proportional to the guy tension.

Then, the weight of the guy and its accumulated ice will exert a downward force on the tower.

Finally, a change in temperature from the temperature at which the guy preload is set, will change the guy preload, thereby changing the vertical force. A drop in temperature will usually increase the guy preload.

(h) Effect of Vertically Applied Forces

The vertical forces are applied to the deflected shape of the tower and the redundant analysis rerun. This process is repeated until the change in deflection becomes small or the change in deflection becomes larger with each trial.

(i) Tower Member Stresses

The axial load on each member of the tower is computed from the bending moment, shear, and vertical force at the section.

The stress is computed by dividing this axial load by the area computed from the diameter and wall thickness of the member.

(j) Final Guy Tension

The guy tension is computed as a catenary under the combined tension force from the tower, temperature differential, preload tension, wind force on guy and weight of guy and ice.

(k) Tower Member Ratios

This is a computation of length/radius of gyration of the members to aid in the manual determination of allowable column buckling of the members. (See Appendix IV.)

(2) Environmental Conditions

(a) Wind Loading

The consideration of wind loading increasing with tower height[21] is of extreme importance in the design of a tall tower. In actuality, the wind increases with height from a standardized anemometer height of 30 foot. For coastal regions, the velocity is given as:

$$V_z = V_{30} \left[\frac{Z}{30}\right]^x$$

where

z = height

x - exponent[21] depending on V_{30}

For V_{30} = 70 knots, x is approximately 0.25. As shown in figure 35, the relative wind force is over three times as great as the wind force resulting from an assumed constant velocity.

(b) Ice Accumulation

Specified ice accumulation is an important consideration in the support structure comparative analysis. The specified ice conditions of one inch of radial ice on the tower, occurring simultaneously with 70 knot winds, are severe but not beyond possible occurrence in tactical application.

The combined wind and ice conditions are considered to occur simultaneously at all times, with no assumptions that ice will be broken off and shed during occurrence of high winds. This assumption may be valid at certain conditions of wind and temperature, but has not been found as a common occurrence.

(3) Sizing of Guys

To minimize bending moments and the resulting stresses in the support structure, the tower supports must be designed and selected in such a manner to allow the structure to be displayed horizontally an amount increasing proportionally with height. Ideally, then, when under maximum environmental conditions, the tower remains linear.

The conducting elements that are also used as guys, and the guy materials, must possess elongation properties, or spring constant, which are compatible with one another.

(4) Tower Configuration Considerations

A transportable tower should be as lightweight as practical for ease of erection and handling. Aluminum, due to its high strength to weight ratio, has been found to be the lightest structural material for ordinary temperature applications by the aircraft industry. Therefore steel towers were not considered in this study.

A savings in weight can be realized by the use of a strong alloy such as 7075-T6 or 7178T-6 in preference to the more common 6061-T6 material. However, the cost of 7178T-6 of approximately $1.27/lb and for 7075T-6 of approximately $1.16/lb must be considered against the lesser cost of 6061T-6 of approximately $.49/lb (for equivalent tubular member).

Towers will usually fail by instability of its column members. Figure 37 shows the allowable compression stress versus the slenderness ratio for 7075-T6, 7178T-6, and 6061-T6 aluminum. It can be seen that it is important to keep the slenderness ratio less than 44 with 7178T-6 aluminum. This is done by keeping the spacing between cross-lacing ties small in relation to the diameter of the leg.

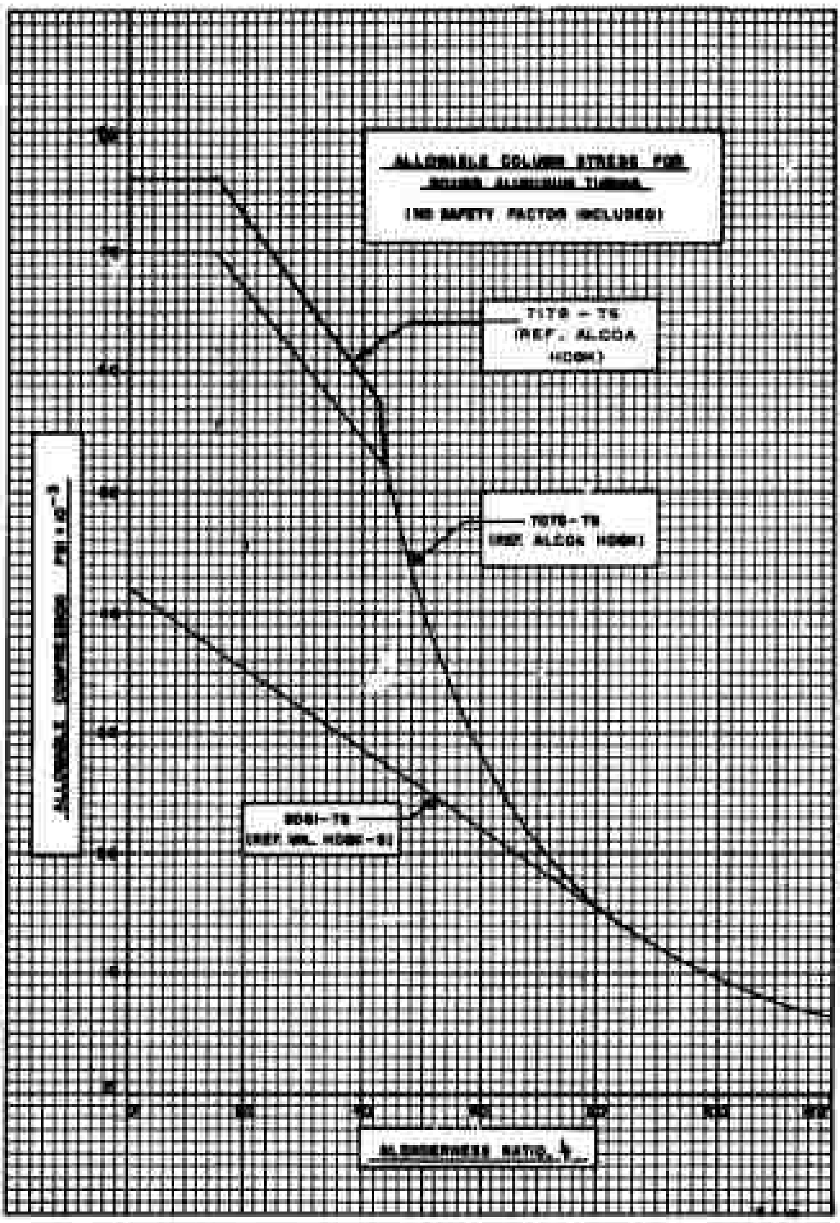


Figure 37. Allowable Column Stress for Round Aluminum Tubing (No Safety Factor Included)

A tower with a fixed base has a high bending moment introduced at the base due to the restraint there. This high bending moment combined with the high vertical load at the base makes the lower members critical. The use of a pivoted base makes the base moment zero where the vertical loads are the highest and results in a lower weight design.

(5) Erectability

To maintain the maximum utilization of available manpower during erection, the structure must be of a basically simple design. This type of transportable equipment is subject to rough handling, and inherent ruggedness of the design if mandatory. Special erection equipment or tools must be kept to a minimum because of the possibility of being lost or damaged.

Site requirements must be considered for antenna erection, and the equipment must be as compatible as possible with various types of terrain. Any special terrain requirements for a particular type of structure must be carefully considered due to the man-hour requirements involved.

The utilization of the 10-man crew must be such that idle time encountered during erection is held to a minimum. Each man should be utilized at a particular task to optimize the erection time.

A prime consideration in the erectability of such a structure is the safety and minimization of risk to associated personnel. The hazards associated with each concept considered must be carefully considered in the comparative analysis.

(6) Transportability

To be classified transportable, the tower structure must be strong, lightweight, stored in a minimal volume, capable of rapid assembly and disassembly, have a minimum of loose pieces, and be of rugged and simple design to withstand operation under tactical situations.

Packaging requirements include the necessity that material to be used first is removed first, and conversely when the system is being taken down. Where possible, all materials are to be re-usable to minimize packaged volume and weight requirements.

The system must be packaged to be compatible with all types of tactical transportation by land, sea, and air in standard military vehicles, and adapt to a standard 463L "Rail" system pallet for aircraft so equipped.

(7) Maintainability Considerations

In determining the optimum configuration for the L F Tactical Antenna, maintainability features to be considered are as follows:

(a) Preventive Maintenance Requirements such as periodic tension checking of guy wires, cleaning requirements of the base plate, or lubricating any moving parts.

(b) Assembly and disassembly time for correction of any structural failures.

(c) Repair time and feasibility of connecting lighting failures on the antenna tower.

(d) Skill levels required to perform maintenance and assembly and disassembly actions.

(e) Special tools requirements for maintenance and installation.

(f) Safety of both installation and maintenance personnel.

(8) Reliability

The reliability evaluation will analyze the mission profile in three operational modes:

(a) Erection

(b) Operation on the site throughout the two years lifetime under all conditions called out in the specifications

(c) Retraction

The equipment design will be reviewed for reliable application of the individual parts, considering applied and rated stresses to insure that adequate safety margins are inherent in the design.

Optimization of the structure will be performed to insure that the design corresponds closely to the reliability required without unnecessary weight. The system effect then is function of reliability and availability. The availability $\left(\frac{MTBF}{MTBF + Downtime}\right)$ is a function of the mean time between failure and the mean down time (scheduled and unscheduled maintenance time plus erection time). All these parameters depend on the complexity of the system. The system with the least auxiliary equipment will have a definite advantage.

(9) Cost

The cost of the system is an important consideration not only in terms of initial investment but also in the logistical cost of maintaining the system. The cost is to be considered as a secondary factor, however, if a system evolves which is considered superior to a degree to warrant the additional cost.

b. GUYS

(1) Materials

The material used for guying the structure must not only possess the desired dielectric properties, but also satisfy necessary structural requirements, such as high strength, minimum elongation for maximum tower stability, flexibility for ease of handling, resistance to moisture absorption, minimum creep properties, a resistance to weathering and sunlight, and capability of operation under a wide range of temperature.

(2) Tensioning and Take-up Devices

Basic functional requirements of a guy cable terminating device include strength capability equal to the guy cable, a take-up mechanism to adjust the length of the guy, and a read-out of guy cable tension. In addition, the device must be simple to operate, rugged, lightweight, and capable of operation in extreme environmental conditions.

c. ANCHORS

Perhaps the most time consuming operation in the erection of the antenna system is the installation of the ground anchors. Important considerations in the selection of an anchor are holding power, weight, ease of installation, suitability to a wide range of soil conditions, and the requirements of special installation equipment. Expendable anchors should be compared against re-usable anchors, taking into account logistics problems, retraction effort and time, and packaging problems.

Also to be evaluated are various types of installation equipment to facilitate placement and removal of ground anchors. They will be considered on the basis of value in installation time requirement saved versus additional weight, volume, and power requirements.

d. GROUND SCREEN

Important considerations of the ground screen in regards to mechanical requirements include weight, handling properties, corrosion resistance, and storage requirements.

The basic concepts of expandable and re-usable ground screens must be evaluated in terms of logistics requirements in addition to the above considerations.

e. RADIATING ELEMENTS

The material to be used for radiating elements in the antenna system must satisfy the electrical considerations discussed in previously as well as possessing mechanical properties such as high strength to weight, compatible elongation properties, good handling qualities, and corrosion resistance.

The conductor diameter requirements include a minimum set by electrical considerations, as well as the tensile strength necessary to provide support to the top level of the support structure. A conductor having the required minimum diameter may possess strength in excess of the structural requirements, as well as excess weight.

The conductor material must have elongation properties or a spring constant (area x modulus of elasticity) which will allow the tower to be displaced horizontally under loading at the radiator support point an amount necessary for the tower to remain linear, thus minimizing stresses resulting from bonding.

Resistance to corrosion and ease of handling and storing must also be considered.

f. LIGHTING SYSTEM CONSIDERATIONS

Of primary importance in considering any type of lighting system is the type of structure involved, the specifications to be met, and the power available at the site. Since the type of structure and the applicable specifications may vary, these areas will be discussed further. The primary power available in all instances will remain at a constant value, 220 volts ac, 3 phase, 400 cycles per second.

In considering the type of lighting fixtures used, several things must be dealt with, the most demanding of which is the amount of light required. If a Federal Aviation Agency (FAA) specification applies, a large flashing beacon is required a the top of the tower and smaller units required at half the tower height (assuming a 300-foot tower - FAA spec. A-2). If less rigid requirements exist, two pair of smaller light fixtures may be used, one flashing pair at the top of the tower and one steady pair at mid-point, or both pair steady. Each type system will be considered with regards to weight, cost, reliability, and ease of installation.

The tower base insulation requirements of the antenna system demand a method of transmitting power across the insulator from the primary power source to the lighting system. The insulation properties required of the insulator are also required of the power transmitting system, that is, 50 kv, 100 amperes at 100 kc. As with the lighting fixtures, each method of transmitting power will be considered with regards to weight, cost, reliability, and ease of operation.

SECTION IV

DATA PRESENTATION AND ANALYSIS

1. GENERAL

This section presents data gathered from the electrical study, the computer analysis of various support structures, and data gathered on various supporting equipment. This gathered data is then compared with the considerations of Section III, and a qualitative comparative analysis is made of all components and techniques. The basis for the recommended system(s) is the result of this analysis.

2. ELECTRICAL CONFIGURATION

During the course of the study seven major configurations were studied. Included in the seven major configurations one hundred minor configurations are represented.

a. CONFIGURATIONS MEASURED

Listed below are model configurations that were measured. See Table VIII for more detailed specifications of the models.

Model No.	Nomenclature	Steps of Variables
1	Standard Umbrella	6
2	Two Foot Umbrella	4
3	Skirted Umbrella	4
4	Umbrella with tapered tower	4
5	Shunt fed umbrella	2
6	Near optimum monopole height at 2 feet	5
7	Inductive top loaded umbrella	30
8	Wound umbrella	6
9	Near optimum monopole height at 3 feet θ and radial length varied	9
10	Near optimum monopole height at 2 feet radial length varied	3
11	Optimum monopole	1

Model No.	Nomenclature	Steps of Variables
12	Discone	4
13	Tee with no. 40 wire only	1
14	Tee with no. 40 wire only ends grounded	1
15	Near optimum monopole height at 2.5 feet	6
16	Tee with tower ends & center simulated	1
17	Tee with tower center simulated	1
18	Tee with flat top	1
19	Triangular monocone	1
20	Square monocone	2

A model of the standard umbrella was constructed at a 100:1 scale using polystyrene sheet supporting material. This type construction was abandoned when the effects of the polystyrene sheet appeared to affect the data and a polystyrene foam construction was adopted. This type construction was subsequently followed throughout the remainder of the program. The elements of the models were constructed from No. 40 wire, which has a diameter of 0.0031 inches. Simulated tower supports were made of one quarter inch brass tube.

With the exception of Model 20, which was scaled to 125:1 because of the large side dimension, all other models were constructed at a 100:1 scale factor (see Table VIII). All models were investigated at 10.1 MHz as our operating frequency scaled to 100:1. This frequency was chosen to avoid the signals of WWV. Model 20 was investigated at 13 MHz, which represented the scaled frequency (see Table VIII).

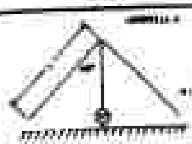
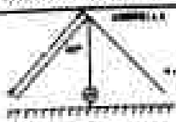
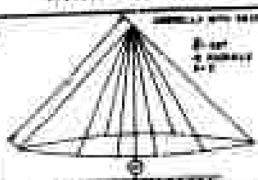
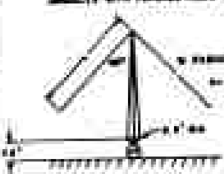
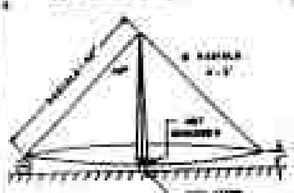
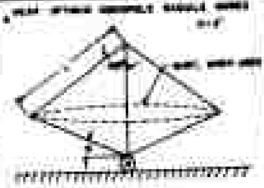
During the last phases of the study some of the models were rebuilt using No. 34 wire, which is nominally twice the diameter of the No. 40 wire initially used to determine the effects of L/D of the elements. This change of wire size made no apparent difference to the data taken initially.

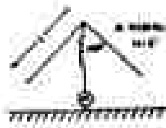
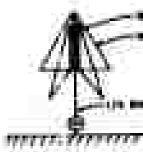
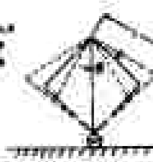
b. Analysis of Data

(1) Discussion of Measured Configurations

Presentation of the significant umbrella and monocone data was made in Section III together with qualitative comparisons based on the three types of mathematical models. The purpose of this subsection is, then, to comment qualitatively on the measured antenna configurations and reiterate and substantiate the conclusions of Section III.

A significant result of the measurements, which is not readily calculable, is the effect of adding a skirt to both the monocone and umbrella structures. Reference to table VIII shows that an approximate 30 percent increase

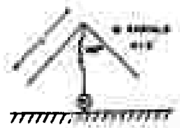
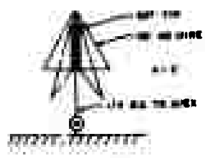
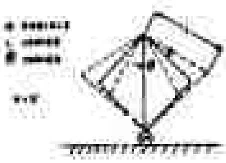
MODEL	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
1 UMBRELLA 		3'-0	910	10,400	180	880	99
		3'-1	6?5	10,400	189	713	117
		3'-4	403.5	13,300	188	683	127
		3'-6	434	13,400	200	402	85.?
		3'-8	434	13,800	211	386	83
		4'-0	380	15,900	222	343	[illegible]
2 UMBRELLA 		3'-0	381	28,700	82	0.0828	33.6
		3'-4	173	37,300	88	0.066	33.7
		3'-6	435	33,800	88	0.058	12.8
		3'-8	173	37,100	73	0.0848	16.63
3 [illegible] 		3'-0	128.1	93,000	288	0.128	148
		3'-3	130	77,730	237	0.338	183.5
		3'-6	128.5	93,200	231	0.153	151
		3'-6	152	84,400	208	0.313	137
4 [illegible] 		4-1/2'	33.1	837,500	202	.0188	88.5
		3-1/2'	28.4	851,000	193	.0088	82
		3'	31.1	818,000	188	.00088	107.5
		2-1/2'	42.8	236,000	188	.0088	88.3
5 [illegible] 	METAL CENTER POLE		[illegible]	820,000	152	.0088	88.5
	DIELECTRIC CENTER POLE		13.45	815,000	320	.00075	16.25
6 [illegible] 	10"	4	93	182,500	82	.019	37.5
	10"	6	83.3	181,500	86	.0288	43.5
	13"	8	73.6	138,500	82	.0286	40.23
	13"	8?	85.1	202,200	100	.0221	43.4
	13"	12?	81.2	165,300	114	.0635	77

MODEL
[illegible] 
[illegible] 
[illegible] 

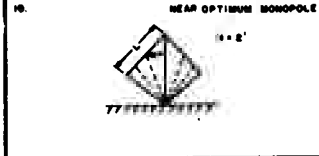
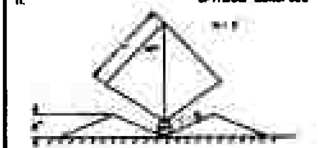
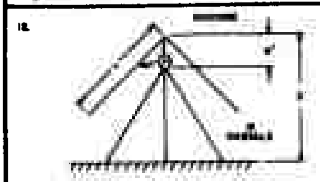
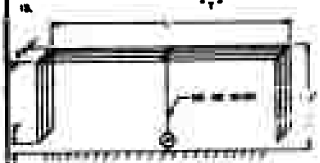
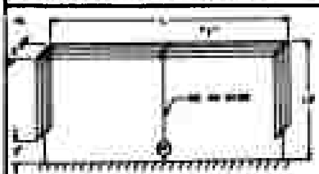
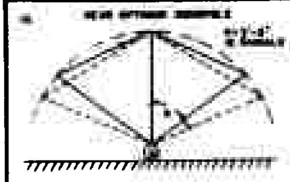
1

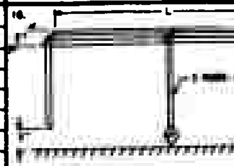
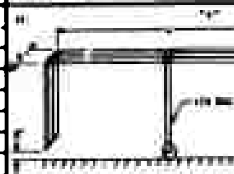
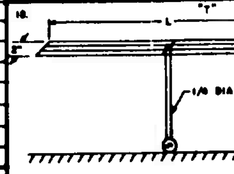
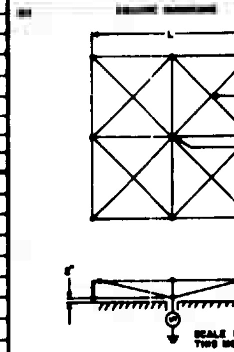
TABLE VIII. MODEL CONFIGURATIONS

Q	ΔF	VmμV	η	ηΔF PRODUCT
970	10,400	180	.950	99
615	16,400	189	.712	117
652.5	15,500	196	.690	107
424	23,800	200	.402	95.7
424	23,800	211	.386	92
390	25,900	220	.340	88.25
261	38,700	62	0.0635	24.6
273	37,000	69	0.064	23.7
425	23,800	69	0.058	13.8
272	37,100	72	0.0448	16.65
108.5	93,000	268	0.159	148
130	77,750	257	0.236	183.5
109.5	92,200	231	0.153	141
157	64,400	208	0.213	137
23.1	437,500	202	.0184	80.5
28.4	351,000	183	.0265	93
31.7	319,000	169	.03365	107.5
42.8	236,000	149	.0405	95.5
11	920,000	252	.0094	86.5
12.45	810,000	238	.009175	74.25
55	183,500	63	.015	27.5
62.5	161,500	96	.0269	43.5
72.8	138,500	93	.0296	40.25
35.7	283,000	104	.0231	65.4
61.2	165,000	124	.0425	70

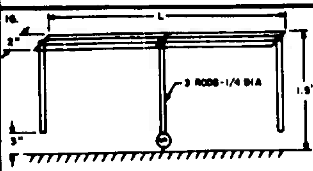
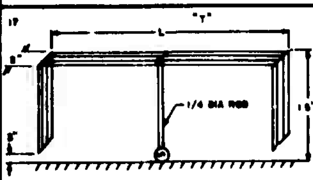
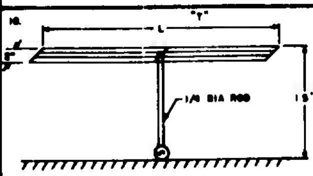
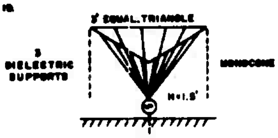
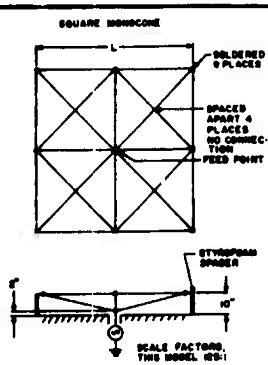
MODEL	INDUCT. IN μF	RADIAL LENGTH	Q	ΔF	VmμV	η	ηΔF PRODUCT
7 UMBRELLA, TOP LOADED 	4.68	3'-0	130	77,700	985	.143	111
	3.4		189	53,400	440	.167	89.4
	2.51		227	44,500	340	.148	66
	1.64		251	40,200	259	.289	116
	0.7		343	29,400	213	.420	123
	4.68	3'-2	128	79,000	1080	.109	87
	3.4		161	62,700	520	.140	87.7
	2.51		167.5	60,300	388	.144	87
	1.64		251	40,250	280	.287	115.5
	0.7		288	35,000	222	.382	133.5
	4.68	3'-4	109	93,000	1000	.088	83
	3.4		116	87,100	619	.112	97.6
	2.51		119	85,000	440	.128	109
	1.64		157	64,300	300	.174	112
	0.7		251	40,500	233	.246	99
	4.68	3'-6	143.5	70,400	855	.1395	98.2
	3.4		146.5	69,000	732	.126	87
	2.51		108.5	92,250	500	.145	134
	1.64		200	50,800	320	.171	87
	0.7		155	65,200	244.5	.218	142.5
	4.68	3'-9	153.5	65,750	561	.09775	64.2
	3.4		185	54,500	790	.1175	64
	2.51		153.5	63,800	523	.138	88.4
	1.64		151	66,900	310	.160	107
	0.7		159	63,500	229	.191	121
	4.68	4'-0	137	68,750	404	.0915	62.8
	3.4		133	76,000	882	.114	86.7
	2.58		136.5	73,950	641	.117	86.65
	1.64		137.5	73,500	341	.132	97.2
	0.7		141.5	71,300	242	.168	120.5
8. UMBRELLA, WOUND  8 RADIALS AT 60° 4 SHOWN	WIRE END GROUNDED	38"	48.4	209,000	73.25	.0097	20.2
	WIRE END OPEN	38"	7.92	1,275,000	50	.001212	26.9
	WIRE END GROUNDED	36"	54	187,000	77.4	.0188	35.2
	WIRE END OPEN	36"	18.2	555,000	9.8	.000126	79.1
	WIRE END GROUNDED	34"	53	190,500	72	.0138	34.8
	WIRE END OPEN	34"	70	1,445,000	3.2	.000404	58.4
9. NEAR OPTIMUM MONOPOLE 	θ						
	40°	3'-0	182	55,500	159	.108	60
		2'-9	168	59,650	142	.102	61
		2'-6	248	40,750	142	.139	56.7
	49°	3'-0	123	82,000	216.5	.1435	117.5
		2'-0	142	71,200	177	.2195	158
		1'-5	183.5	55,000	129	.151	83
	60°	3'-0	274	36,900	239	.446	164.5
		2'-9	147.5	68,600	218	.208	142.5
		2'-6	182.5	55,300	208	.163	90

2

MODEL	INDUCT IN µH	RADIAL LENGTH	Q	ΔF	Vm µV	η	ηΔF PRODUCT
10. NEAR OPTIMUM MONOPOLE 		2'-4	315	32,100	77	0.058	18.6
		2'-2	272	37,100	70.5	0.0466	17.3
		2'	286	35,300	70.0	0.057	20.15
11. OPTIMUM MONOPOLE 		2'	221	45,750	156	0.174	79.5
12. 	0	3'-0	48.1	210,000	138	.0313	65.6
	5	2'-6	50.75	199,000	375	.0286	56.8
	5	3'-0	42	241,000	590	.0214	51.6
	5	3'-6	40	253,000	580	.021	53 1
13. "T" 		12'	44.85	225,000	299	0.105	236
14. "T" 		12'	39.2	258,000	83	0.0036	9.3
15. NEAR OPTIMUM MONOPOLE  θ							
60°			64.8	156,000	150	.054	84.4
50°			70	144,000	143	.0559	80.5
40°			75.9	133,000	130	.0496	66
30°			60.1	168,100	100	.035	58.8
20°			55.75	181,000	92	.0293	53
10°			45.4	222,500	64	.0174	38.7

MODEL
16. 
17. "T" 
18. "T" 
19. 
20. 

1

ΔF	VmμV	η	ηΔF PRODUCT	MODEL	INDUCT IN μH	RADIAL LENGTH	Q	ΔF	VmμV	η	ηΔF PRODUCT
2,100	77	0.058	18.6	16. 		12'-0	313	32,300	270	.435	140.5
7,100	70.5	0.0466	17.3								
5,300	70.0	0.057	20.15								
5,750	156	0.174	79.5	17 		12'-0	200	50,000	272	.292	148
10,000	138	.0313	65.6	18. 		12'-0	184	55,000	218	0.244	134.5
9,000	375	.0286	56.8								
1,000	590	.0214	51.6								
3,000	580	.021	53.1								
5,000	299	0.105	236	19. 			262.5	38,500	81	0.0756	29.15
8,000	83	0.0036	9.3	20 	F_o = 13MC	8'-0	8	1,625,000	280 Emc= 1.4MV/M	.0297	373
6,000	150	.064	84.4		F_o = 10.1MC	8'-0	11.35	890,000	230	.007225	64.25
4,000	143	.0559	80.5								
3,000	130	.0496	66								
8,100	100	.035	58.8								
1,000	92	.0293	53								
2,500	64	.0174	38.7								

2

in ηXBW is obtained with the skirt. Furthermore, the skirt need not be made of conductors of larger diameter than the umbrella or cone wires. The skirt apparently provides increased capacitive loading in the mast or the base cone.

The umbrella model was measured with and without a tapered mast section. The presence of this section seemed to insignificantly change the measured η XBW.

In certain cases the comparative efficiencies of some of the configurations of table VIII seem to be extraordinarly low and differ by an order of magnitude. This is because these lower efficiency (as measured) configurations were measured with a series 10-ohm registor at the antenna terminals. The configurations include the square monocone, the shunt fed umbrella, and the umbrella with tapered mast.

A shunt fed umbrella configuration was tried to attempt to approximate feeding an antenna with a slice generator. The η XBW results were about 20 percent below the standard umbrella. If the antenna had been more ideally fed, such as with multiple generators spaced around the periphery at the skirt, the effect at the shunt skirt capacitance could probably have been minimized. As it was, the low skirt height required to feed the antenna appeared as a shunt capacitance directly across the single generator. Also, because of ohmic losses in the wires, it was not possible with a single generator to provide uniform circumferential excitation of the structure.

An umbrella model loaded near the top of the mast with a series inductance was measured (see Table VIII). The plan was to measure the electrical length in a region sufficiently up from the mast base to be in a region where appreciable current was flowing and to be able to take advantage of the effective impedances transformation of the mast. The data is somewhat scattered, but the results indicate that the η XBW is of the same order as that of the standard umbrella and is best with minimum inductance.

A "wound" umbrella configuration was measured where the umbrella portion was made of a continuous wound wire with 6 turns equally spaced radially in azimuth. The purpose of this configuration was to increase the overall electrical length in much the same manner as a helix. The ηXBW results were poor, having values only 30 to 40 percent of the standard umbrella. The efficiencies are seen to be low. The configuration was measured with the wire end open and then grounded to the mast. The results indicate that the ohmic losses at the continuous wire are large enough to decrease the efficiency. One interesting feature of the data is that the measurement with the wire open indicated the lowest efficiency and the maximum ηXBW. This indicates that the electrical length of the open-wire-end wound portion was greater (lower reactance) but the electrical length at the antenna in terms of effective height was probably less. Also, grounding the wire end may have effectively fed the wound portion of the antenna at both the base and the top, thus increasing the effective height somewhat.

Of all the configurations measured, the square monocone exhibited the greatest ηXBW (373 at scale frequency of 13 MHx). This is to be expected considering the large land area it covers. There is no elementary means of analytically evaluating its performance. As a check, it was measured also at 10 MHz, which is the scale frequency for the other configurations. The fall-off at η XBW is twice as great as would be expected by $(f/fo)^4$. Of course, it is not suitable for the Loran-D application because of its size.

Several "T" antenna configurations were measured. The "T" antenna without the folded ends has a measured value at η XBW at 134.5 (see Table VIII). Considering an effective height of about 0.95 of the physical height

$$R_a = 40\ (\beta h)^2\ (he/Ht)^2\ =\ 0.33$$

The characteristic impedance, Z_o, of the strip (strip width - 2 times diameter at a circular conductor) is 260 ohms. Two strips in parallel give 130 ohms. Calculating η x BW by

$$\eta XBW = \frac{2R\ f\ \sin^2 kl}{kl\ Z_o + \frac{Z_o}{Z}\ \sin 2\ kl}$$

when kl is 0.384 radians or 22 degrees, η x BW = 92.8

The above formula does not take into account the fringing fields off the ends of the strip, so a value of 134.5 measure seems reasonable. As inferred in Section III, the "T" antenna requires too much land area to be suitable for Loran-D. The "T" antenna with folded ends provide about a 5-6 percent increase in ηXBW. The value of ηXBW equals 236 measured for the "T" antenna with the wire mast made at No. 40 wire is not valid. This length of wire has an ohmic loss at about 4 ohms.

The monocone (monocage or near-optimum monopole) data has been discussed previously. There is close correspondence between calculated and measured data. The optimum monopole configuration, conceived as an optimum design from a statics point of view, proved to be inferior to the monocone due to the added shunt capacitance at the elevated portion of the ground plane.

No mathematical analysis was performed on the discone configuration of table VIII. This configuration proved to be inferior to the umbrella or monocone configurations by about 50 percent. This configiruation seemed promising at its conception because the inverted conical base cone section looked as if it would support a more favorable current distribution than an umbrella, and that the proximity of the umbrella wires to those at the cone would increase the load capacity. The probable reason for its being inferior is due to the fact that the top-fed inverted-cone probably present a low impedance path to ground, whether or not the basis of the cone was grounded.

3. DESIGN RECOMMENDATIONS

The conclusions of the analysis of the measured data are in agreement with those of Section III 2 a (4). The measured data for the most promising configurations for the Loran-D space requirements, namely the umbrella and monocone configurations, is in substantial agreement with calculations performed in this document and the referenced sources. The calculations were relied upon heavily for variation of characteristics with parameter change. The umbrella is chosen as the optimum configuration and the following optics are proposed from an electrical point of view and are based on the umbrella design factors summarized in Section III 2 a (4).

a. Increased ηSBW options (over conventional 300-feet, 9-wire umbrella)

(1) η XBW 133

Tower height:	300 feet
Number of wires:	12 w/o skirt
Base radius:	345 feet
Umbrella angle:	49 degrees

The land area increase over that of a 300-foot radius is 33%.

(2) η XBW 170

Tower height:	300 feet
Number of wires:	12 with skirt of same conductor diameter as wires
Base radius:	345 feet
Umbrella angle:	49 degrees

b. η XBW 100 system options

(1) η XBW 100

Tower height:	275 feet
Number of wires:	12 w/o skirt
Base radius	300 feet
Umbrella angle:	47.5 degrees

(2) η XBW 100

Tower height:	250 feet
Number of wires:	12 with skirt at same conductor diameter as wires
Base radius:	300 feet
Umbrella angle:	45 degrees

4. MECHANICAL CONFIGURATIONS

Due to the fact that the umbrella antenna with modifications is the optimum electrical configuration, the mechanical configuration study is concentrated on satisfying the parameters of that array.

Comparative analysis of various techniques and concepts consider components which are practical, capable of satisfying the system specifications, and capable of adaptability to a tactical environment. The capability of rapid and reliable operation by military personnel in the field is a prime consideration.

a. SUPPORT STRUCTURES INVESTIGATED

The following types of support structures are compared as to their applicability to the requirements of the antenna system and compliance with the required specifications. Several types were given relatively limited consideration because of obvious limitations. Inflatable types which are proposed are compared using data supplied by reputable manufacturers as a basis for comparison. Detailed structural analysis of applicable types of structures was performed as a basis of comparison.

Types of structures investigated are discussed in the following paragraphs:

(1) Triangular Scaffold Type Structure

The triangular Snap-Out tower, manufactured by Up-Right Tower Co., is a development of portable scaffolding structures used in the present antenna system, which is the basis for comparison in this study.

The tower is comprised of 3-foot long interchangeable sections. Leg members are of 7178-T6 aluminum, with swing-bolt connections at each end. Horizontal members are of the same alloy and hinge at mid-span for compact storage as shown in figure 38. Diagonal members are stainless steel aircraft cable, which are tensioned when the horizontal members are extended and locked.

Tower erection is begun by assembly of a 30-foot portion of the tower on the ground. This portion of the tower is tilted to the vertical by hand and temporarily guyed. The remainder of the tower is assembled by hoisting 3 sections at a time with a light-weight davit assembly to a man at the top of the assembled tower as shown in figure 39. Guys are added at specified intervals during erection. Personnel on the ground pull the succeeding sections up to the high man by means of a tag line.

To critically evaluate the standard tower as it exists, a computer analysis was performed. A basic requirement of a safety factor of two with respect to failure by buckling (see Appendix IV) is assumed to be needed. Tower parameters inputed are shown in table IX, and guy parameters in tables X and XI. Computed tower data is shown in table XII, and computed guy data is in table XIII. A representative computer input data sheet and print-out (run #15) is shown in Appendix II.

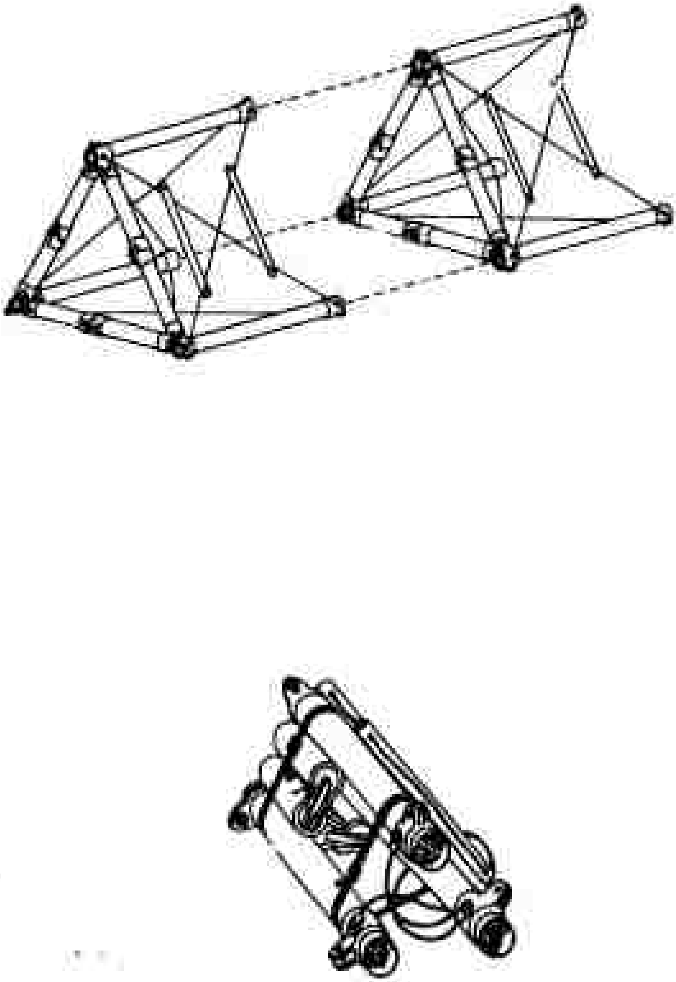


Figure 38. Snap-Out Tower

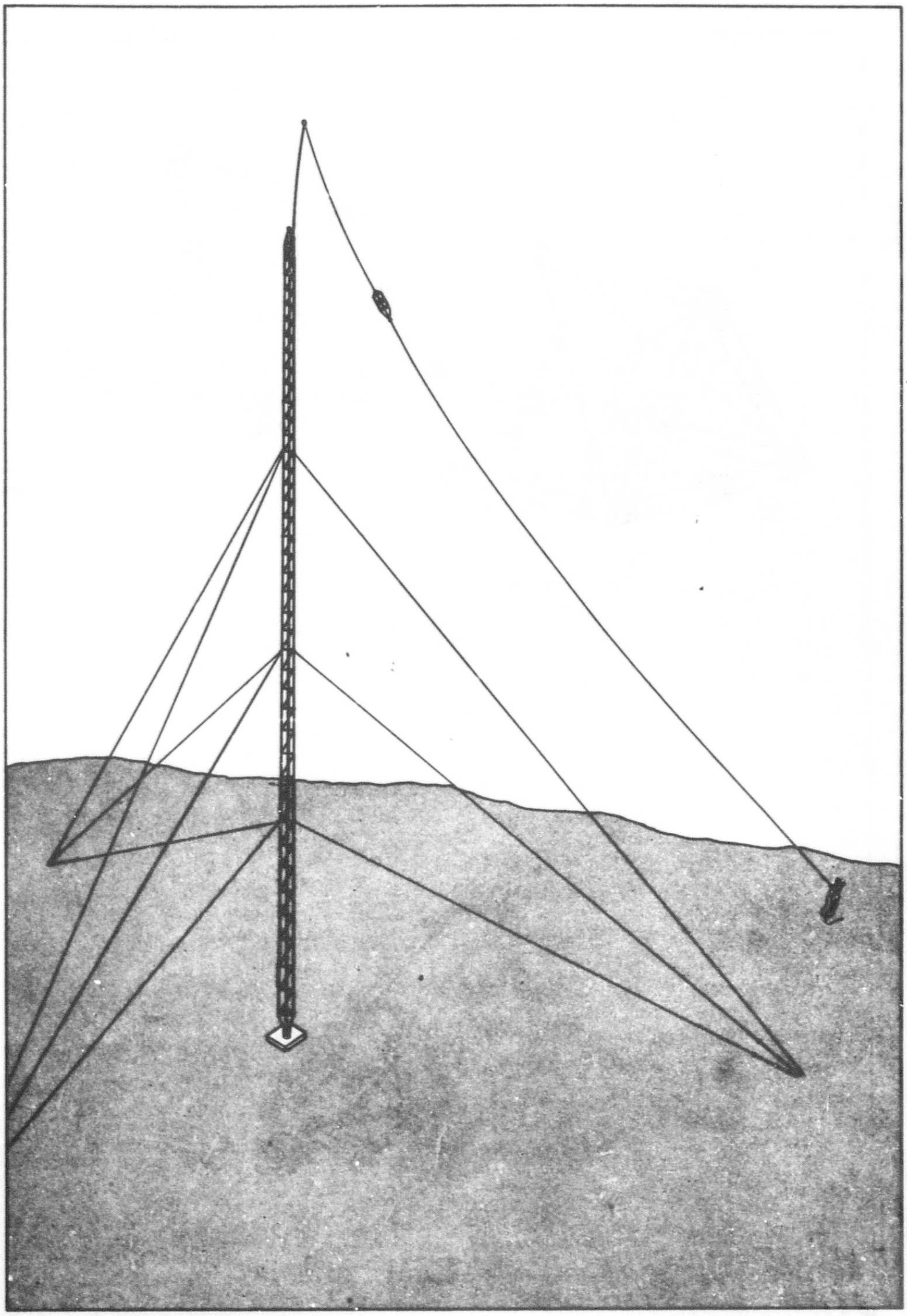
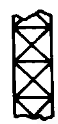


Figure 39. Snap-Out Tower Erection

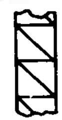
TABLE IX. TOWER CONFIGURATION

TOWER CONFIGURATION	SECTION CODE	LEG MEMBERS		DIAGONAL MEMBERS		HORIZONTAL MEMBERS	
		DIA., IN.	WALL THK., IN.	DIA., IN.	WALL THK., IN.	DIA., IN.	WALL THK., IN.
I	3	2	.095	.316	.158	2	.058
II	3	2	.125	.316	.158	2	.058
III	5	2.5	.065	2.0	.058	2	.058
IV	5	2.5	.095	2.0	.058	2	.058
V	5	2.5	.083	2.0	.058	2	.058
VI	5	2	.125	2.0	.058	2	.058
VII	5	2	.095	1.25	.058	1	.058

SECTION CODES



TRIANGULAR 03
SQUARE 04



TRIANGULAR 05
SQUARE 06

TABLE X. GUY CONFIGURATION

S = TOWER TO ANCHOR, FT.
AE = SPRING CONSTANT
T = PRETENSION, LBS.

GUY CONFIGUR-ATION	GUY NUMBER 1			2			3			4			5			6		
	S	AE(10^3)	T_1	S	AE(10^3)	T_1	S	AE(10^3)	T_1	S	AE(10^3)	T_1	S	AE(10^3)	T_1	S	AE(10^3)	T_1
A	305	111	100	303	400	2,000	301	400	2,000	148	400	2,000	146	400	1600	144	400	1,600
B	305	322	400	303	720	3,000	301	720	2,600	148	720	2,200	146	720	1,600	144	720	1,600
C	306	322	400	303	720	3,000	301	720	2,600	148	520	2,200	146	400	1,600	144	400	1,600
D	305	485	500	303	940	3,000	301	940	3,000	148	720	2,500	146	520	2,000	144	400	1,500
E	300	485	500	300	2,400	4,000	200	2,400	4,000	200	1930	4,000	100	1,590	4,000	100	1,120	4,000
F	300	485	500	300	940	3,000	200	940	3,000	200	720	2,500	100	520	2,000	100	400	1,500
G	300	180	450	300	720	2,700	200	720	2,700	200	520	1,900	100	520	1,900	100	400	1,500
H	305	180	450	303	720	2,700	301	720	2,700	148	520	1,900	146	400	1,500	144	400	1,500
K	306	240	600	303	940	2,700	301	720	2,700	148	520	1,900	146	400	1,500	144	400	1,500
L	300	111	200	300	400	2,000	200	400	2,000	200	400	2,000	100	400	2,000	144	400	1,500
M	300	180	450	250	940	2,700	248	400	2,000	100	400	2,000	98	400	2,000	100	–	–
N	306	180	450	303	9.4	2,700	301	720	2,700	148	520	2,700	146	400	1,500	144	400	1,500
O	348	180	450	346	9.4	2,700	344	720	2,700	148	520	2,700	146	400	1,500	144	400	1,500
P	348	240	600	346	9.4	2,700	344	720	2,700	148	520	2,700	146	400	1,500	144	400	1,500

TABLE XI. ROPE PROPERTIES

ROPE	DIAMETER, INCHES	AE (10^3)
GLASTRAN	7/32	240
"	1/4	300
"	5/16	400
"	3/8	520
"	7/16	720
"	1/2	940
"	9/16	1,120
"	5/8	1,490
"	11/16	1,590
"	3/4	1,930
"	13/16	2,400
ALUMOWELD	3°10	485
PHOS. BRONZE	1/8	111
PHOS. BRONZE	3/16	322

(a) Run No. 1

The standard antenna structure is comprised of tower configuration I and guy configuration A. A plot of tower displacement under load is shown in figure 40. As shown, the tower is displaced non-linearly with a maximum delfection of 8.8 feet at the top. Resulting leg stresses, shown in table XII, exceed the design stress (safety factor of two included) see Appendix III. Diagonal and horizontal tower members are within design stress limits. Also, the guys are overstressed above the desirable limits of one-half the breaking strength at the top four guy levels, as indicated in table XIII. The analysis of this computer run shows that the tower is of optimum configuration, and guy sizes are not of proper diameter to limit tower deflection under load. The high leg stresses result not only from the less than optimum tower configuration, but from the non-linear deflection of the tower. The standard configuration, as exists, provides a minimal margin of safety, therefore, the following computer runs were made in order to optimize the standard configuration to bring stress and loading values within acceptable limits.

(b) Runs 2, 3, and 4

These computer runs were made varying d' and h' as shown in table 9. Figures 41, 42, and 43 indicate no noticable change in tower deflection, and leg member and guy stresses are still excessive.

(c) Runs 5, 6, and 7

Run 5, 6, and 7 were made with varying guy and tower configurations. Although guy loadings were brought generally within limits, leg stresses were still excessive and the tower deflection plots, shown in figures 44, 45, and 46, are non-linear, although total deflections are diminished to 2 to 3 feet maximum.

(d) Run No. 8

Run No. 8, using tower configuration I and guy configuration H, resulted in a more linear tower deflection as shown in figure 47. Guy loadings are close to specified limits, but tower leg stresses are still excessive.

(e) Run No. 9

Run No. 9, using tower configuration II and guy configuration H, resulted in tower leg stresses only slightly over the specified limit, and guy loadings nearly within limits. The deflection plot of the tower in figure 48 shows that the top of the tower deflected to 6 feet, which results in a somewhat non-linear tower deflection.

(f) Run No. 10

In Run No. 10, tower configuration II and guy configuration K combine to give a near optimum combination within specified design stresses and loadings with the exception of the 9 radials supporting the tower at the top, which have a safety factor of 1.6. The maximum tower deflection as shown in figure 49 is 4.4 feet, and the tower is in a nearly linear position under loading. Table shows a direct comparison of Run No. 1, the standard antenna, and Run No. 10, the optimized standard antenna.

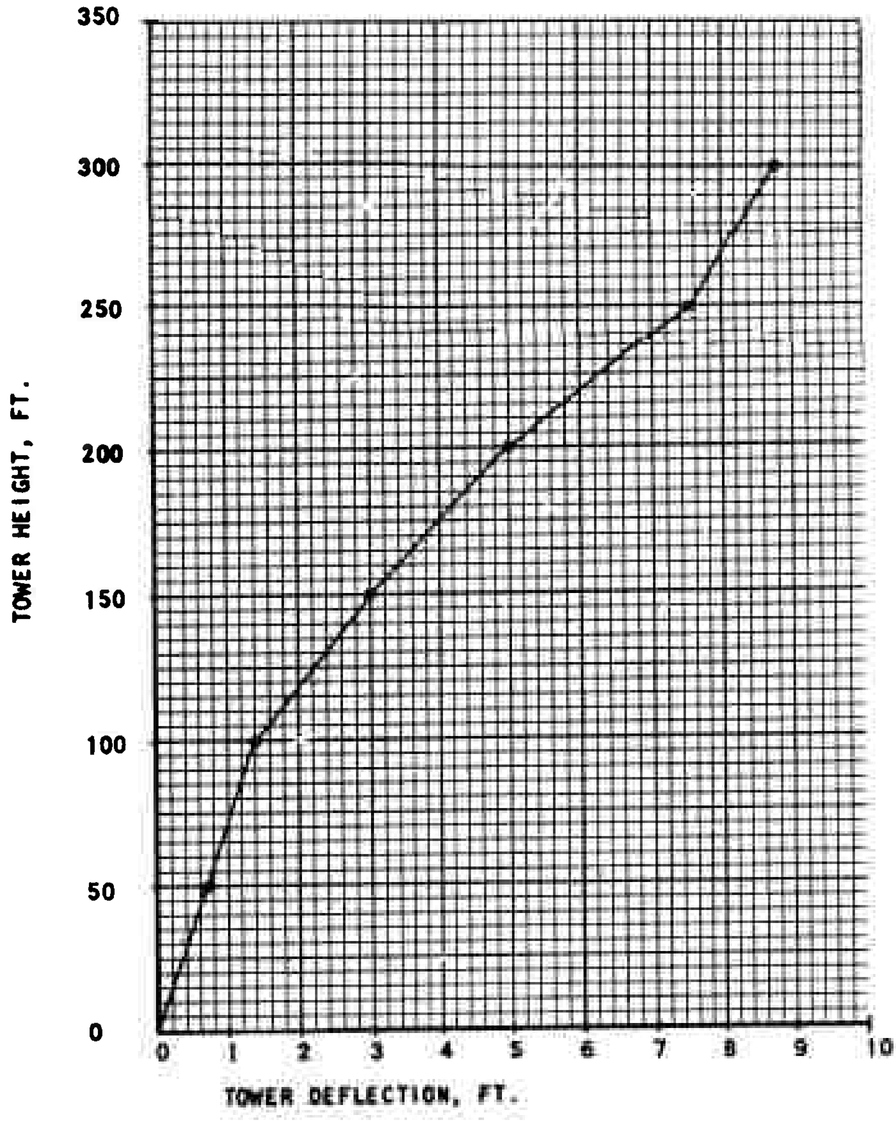


Figure 40. Computer Run #1

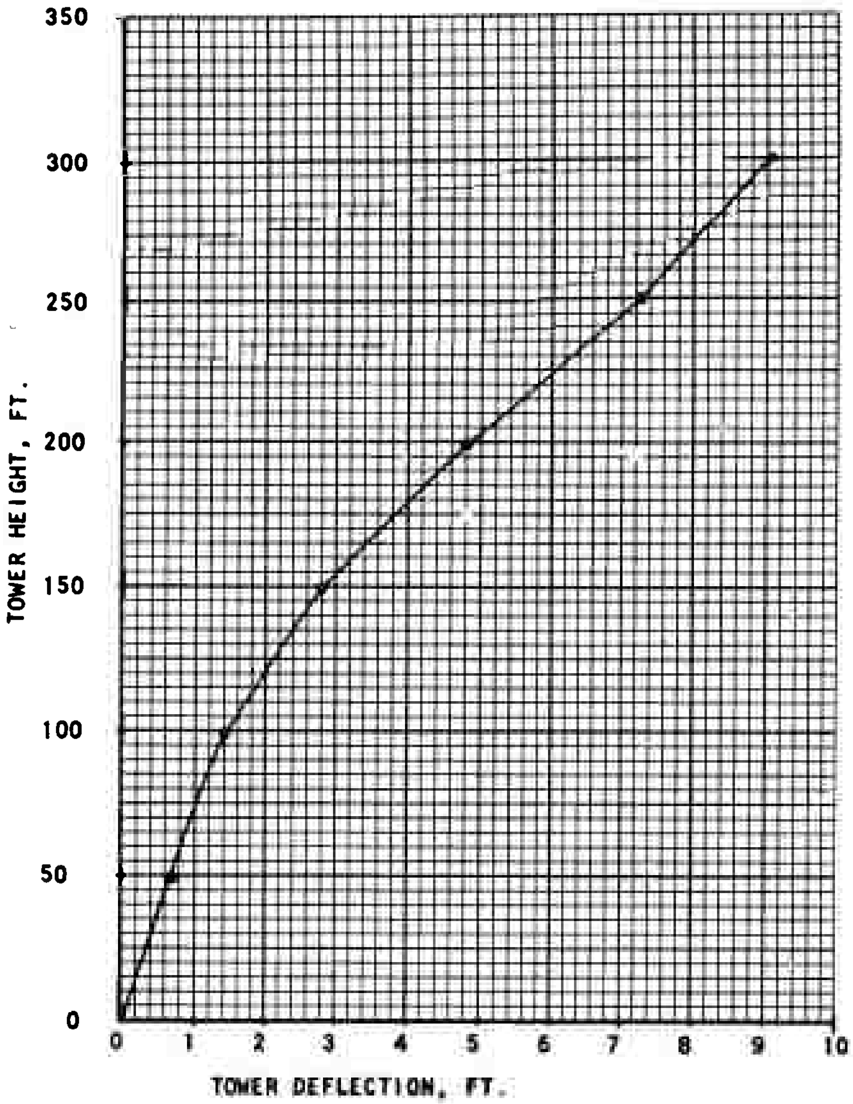


Figure 41. Computer Run #2

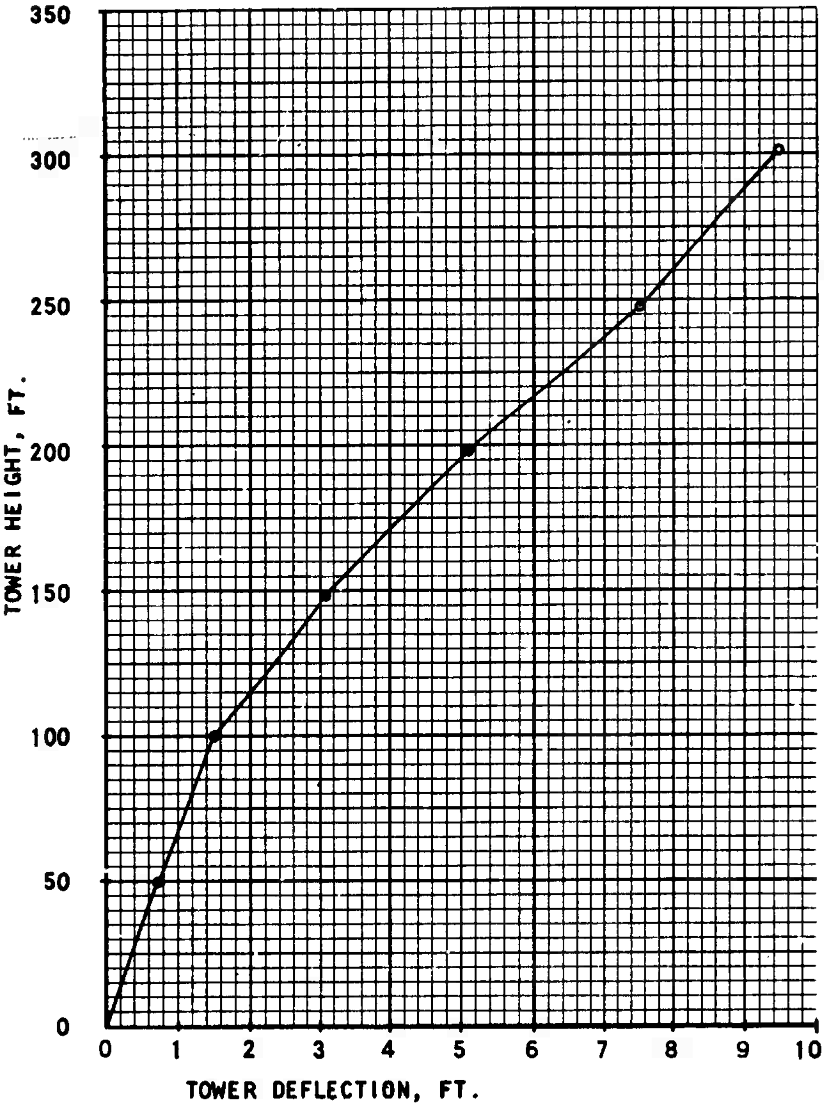


Figure 42. Computer Run #3

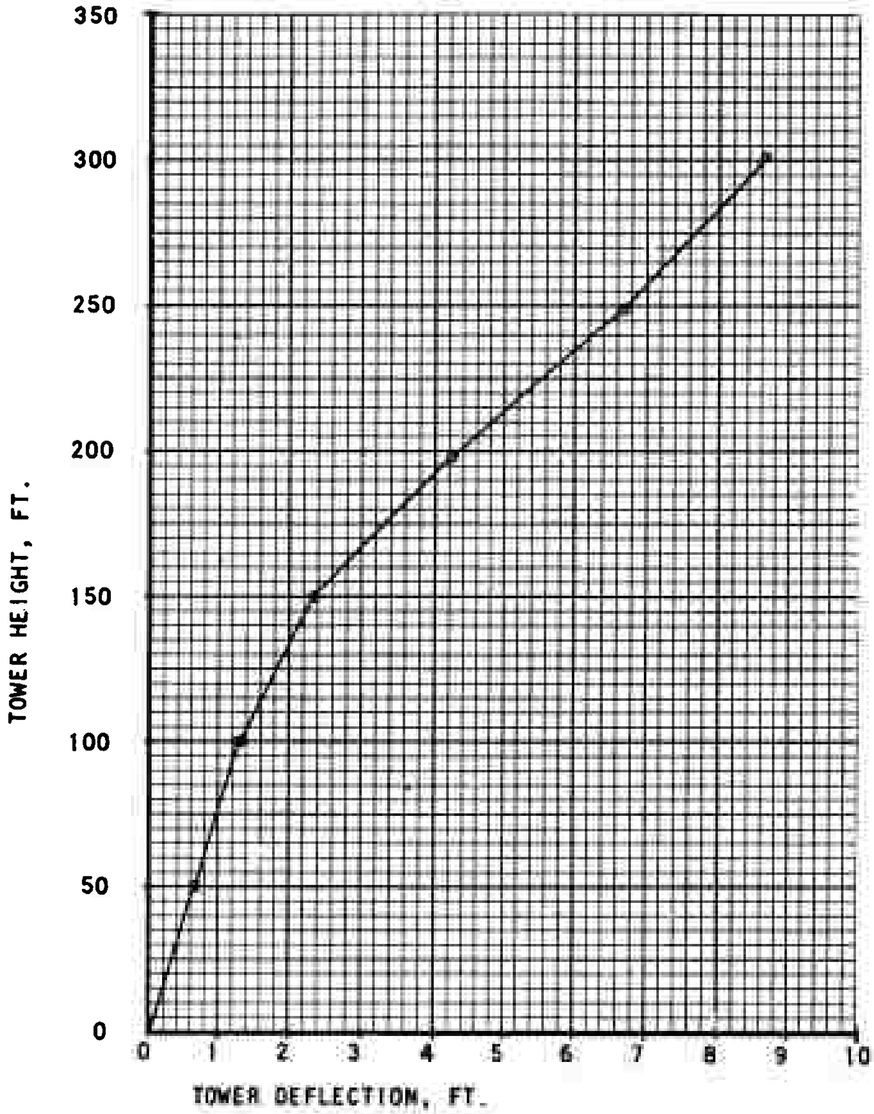


Figure 43. Computer Run #4

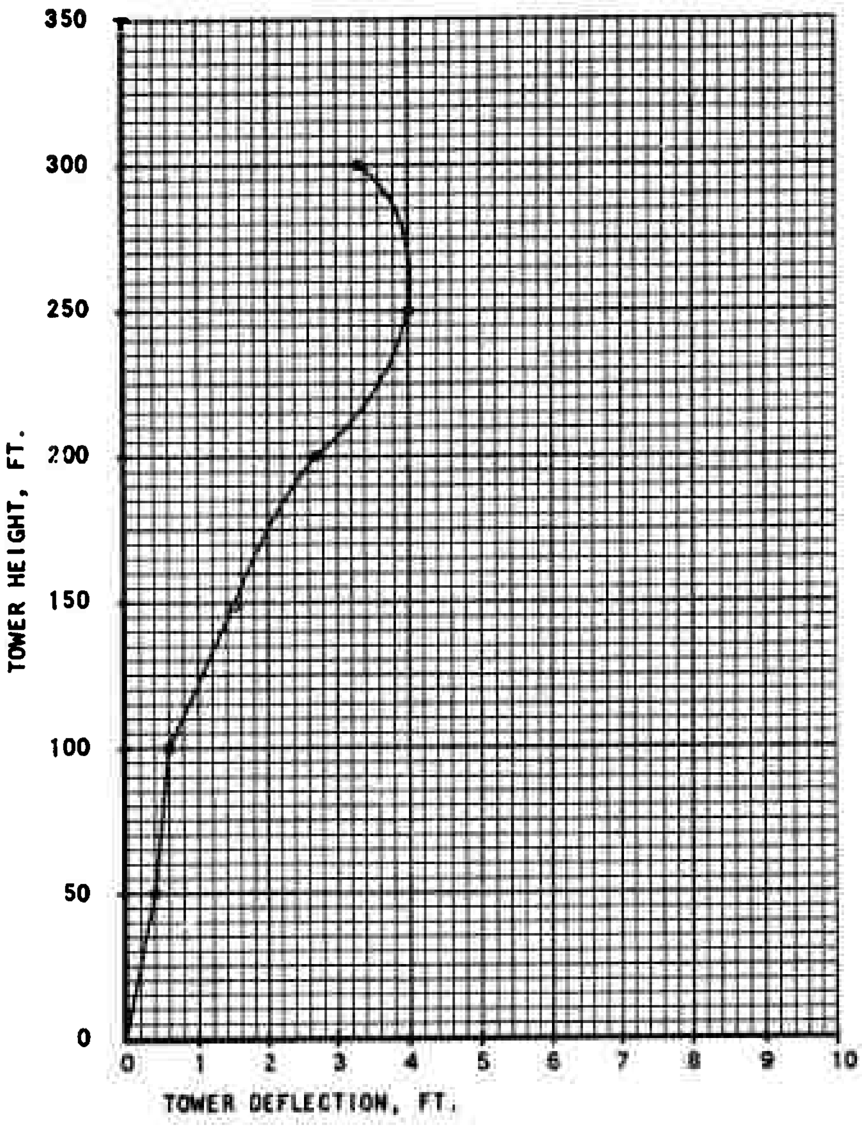


Figure 44. Computer Run #5

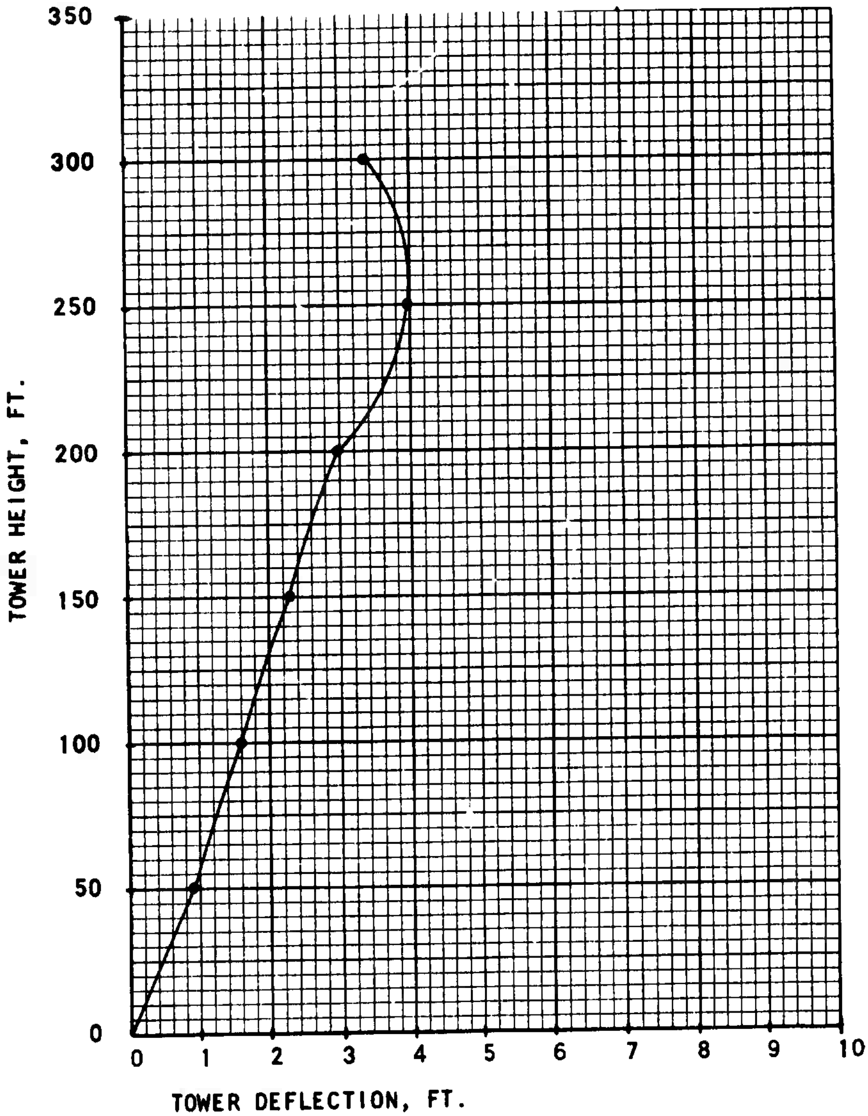


Figure 45. Computer Run #6

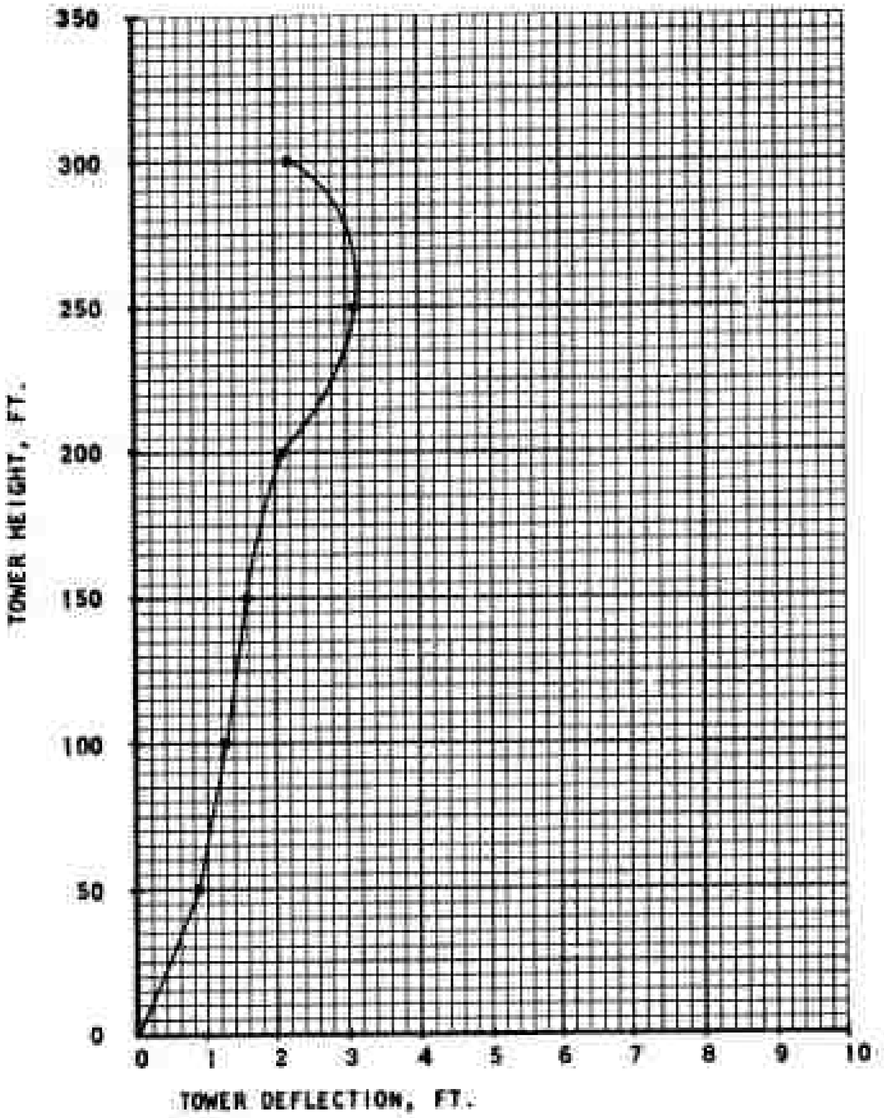


Figure 46. Computer Run #7

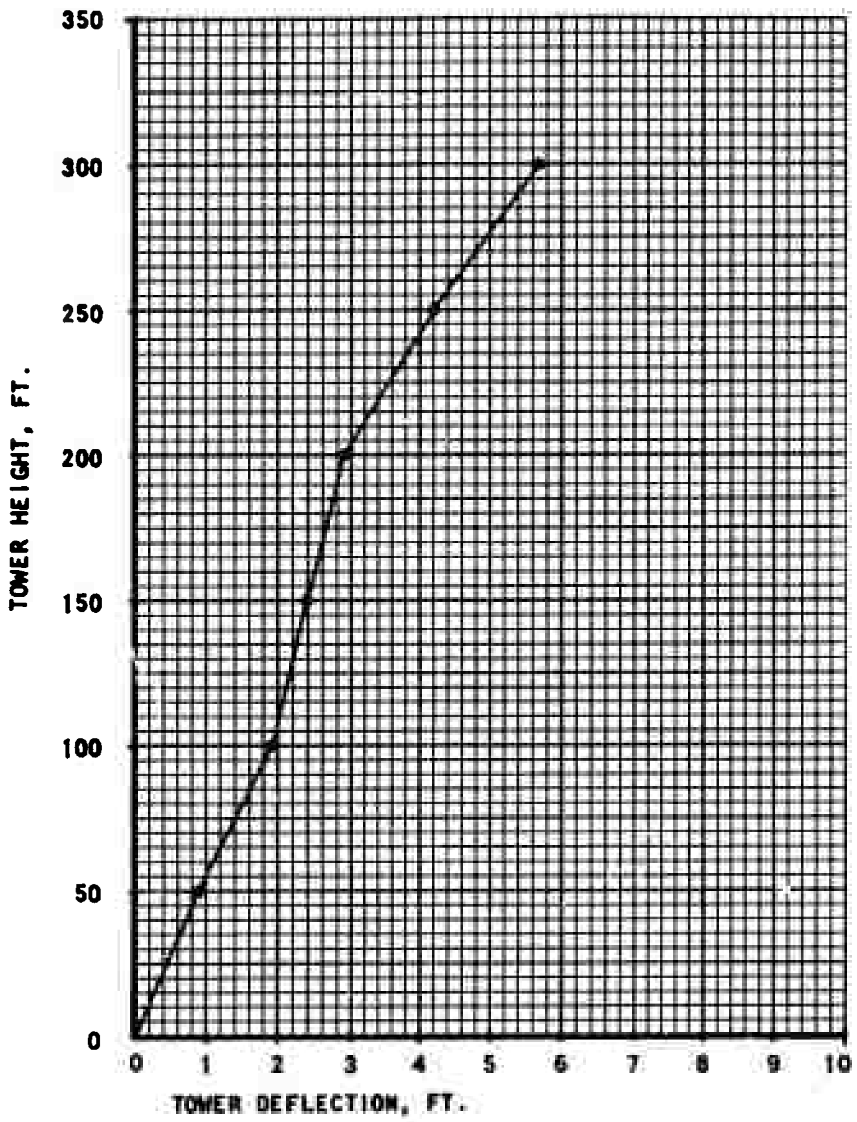


Figure 47. Computer Run #8

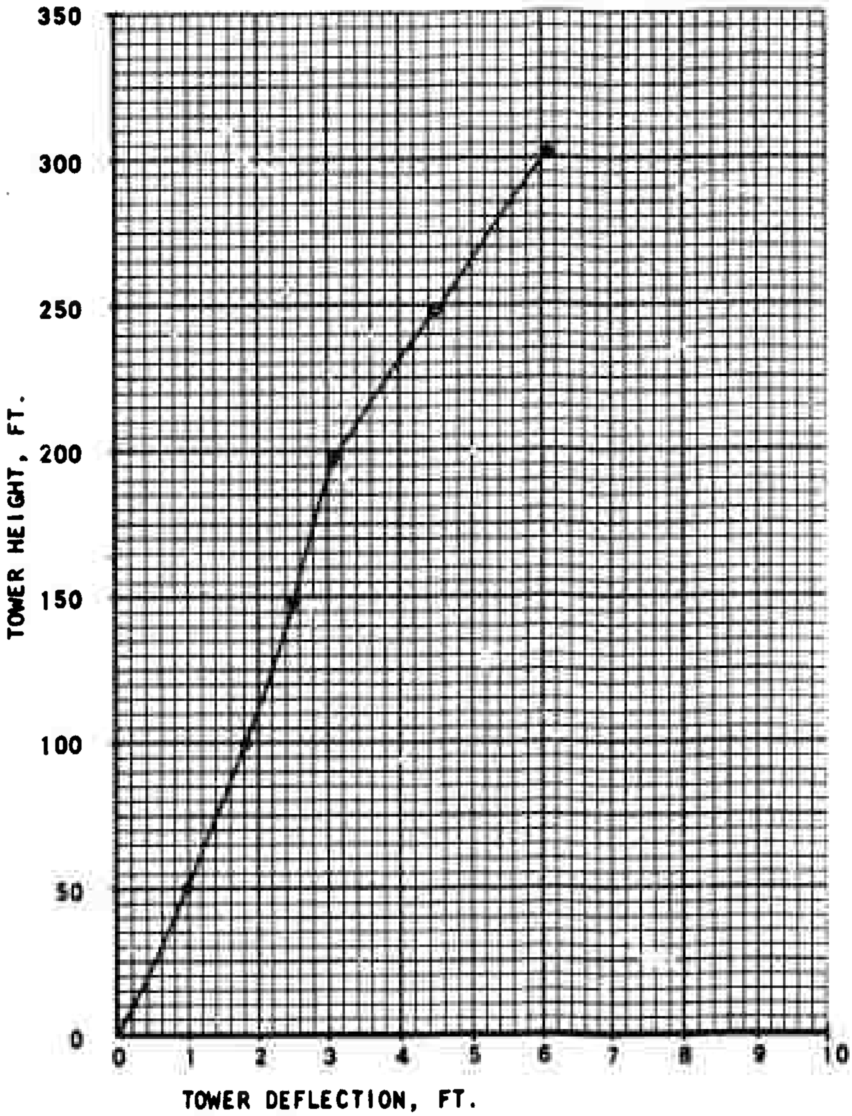


Figure 48. Computer Run #9

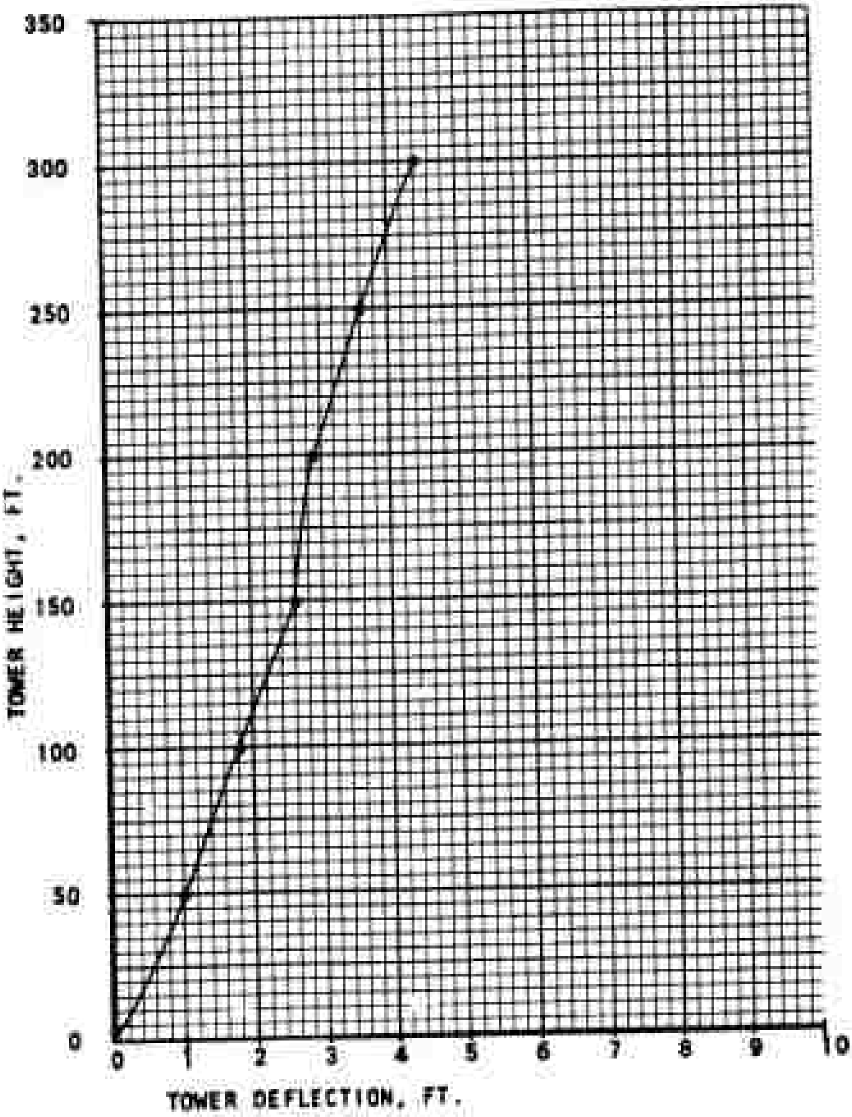


Figure 49. Computer Run #10

The use of the optimized configuration of the standard antenna will result in a 157 pound weight increase due to larger guys, and a 210 pound increase due to tower configuration changes necessary to comply with specified requirements with a design safety factor of two.

(g) Run No. 11

In Run No. 11, guy configuration N and tower configuration II were used with 12 radial antenna wires at the top as opposed to 9 for the standard antenna. As shown in tables XII and XIII, tower stresses and guy loads are within acceptable limits. Figure 50 shows that the tower is displaced in a linear manner under load. The addition of three more antenna radiators does not exceed the capabilities of the tower.

(h) Run No. 12

Run No. 12 represents the standard antenna configuration with the exception that the angle between the radiators and the tower is 49° rather than 45°. Tower configuration II is used, as is guy configuration P. The tower remains relatively linear under loading as shown in figure 51, and tower member stress levels shown in table XII are at acceptable levels, as are the guy loads shown in table XIII.

(i) Run No. 13

Run No. 13 utilizes tower configuration II and guy configuration O. Twelve radiators are attached to the top of the tower at a 49° angle between the tower and radiators. As shown in tables XII and XIII, tower member stresses and guy loading are at acceptable levels, and figure 52 indicates that the tower deflects in a linear position.

(j) Run No. 14

In Run No. 14, 12 radial antenna wires are used, with a tower shortened to 275 feet. Tower configuration II is used with guy configuration M, which has five guy levels, as opposed to six for all previous runs. Tables XII and XIII show that tower member stress levels and guy loads are within acceptable limits. The tower deflects linearly as shown in figure 53.

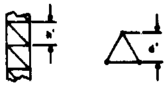
(k) Run No. 15

In Run No. 15, the tower in configuration II is shortened to 250 feet and guy configuration M is used. Twelve radiator wires are used with a circumferential skirt wire located approximately 3/4 down from the top of the radiators. As shown in tables XII and XIII, tower stresses and guy loads are well within specified limits. Figure 54 shows that the tower deflects linearly to a maximum of only 3 feet under loading.

(l) Run No. 16

Run No. 16 uses tower configuration I and guy configuration H with the ice loading omitted. Tables XIII and XIV show that the tower stresses and guy loads are very low, with an overall safety factor in the order of four of one. This run was made for a comparison with inflatable types which cannot withstand the specified ice conditions. Although no further runs were made to lighten and optimize

TABLE XII. TOWER COMPUTER INVESTIGATION



COMPUTER RUN NUMBER	CONFIGURATION		d' IN.	h' IN.	LEG MEMBER			DIAGONAL MEMBER			HORIZONTAL MEMBER		
	TOWER	GUY			MAX STRESS PSI	L/r	DESIGN STRESS PSI	MAX STRESS PSI	L/r	DESIGN STRESS PSI	MAX STRESS PSI	L/r	DESIGN STRESS PSI
1	I	A	36	36	31,235	52	19,000	36,414	--	40,800	6017	54	17,500
2	I	A	36	42	30,121	61	13,750	37,843	--	40,800	5749	54	17,500
3	I	A	42	42	30,004	61	13,750	36,180	--	40,800	5975	63	13,000
4	I	A	30	36	30,790	52	19,000	34,895	--	40,800	5212	45	25,000
5	I	B	30	30	38,375	43	26,250	37,150	--	40,800	6127	45	25,000
6	I	C	36	36	33,126	52	19,000	36,330	--	40,800	5990	54	17,500
7	I	D	30	30	41,616	43	26,250	37,812	--	40,800	6231	45	25,000
8	I	H	36	30	33,432	43	26,250	33,521	--	40,800	5998	54	17,500
9	II	H	36	30	27,579	44	26,000	37,247	--	40,800	6669	54	17,500
10	II	K	36	30	25,591	44	26,000	39,004	--	40,800	6968	54	17,500
11	II	N	36	30	26,226	44	26,000	39,404	--	40,800	7036	54	17,500
12	II	P	36	30	25,637	44	26,000	39,154	--	40,800	6993	54	17,500
13	II	O	36	30	25,893	44	26,000	39,559	--	40,800	7083	54	17,500
14	II	M	36	30	26,207	44	26,000	38,071	--	40,800	6798	54	17,500
15	II	M	36	30	21,386	44	26,000	30,555	--	40,800	5485	54	17,500
16	I	H	36	36	13,179	43	26,250	17,878	--	40,800	2951	54	17,500
17	I	H	36	30	8,670	43	26,250	2,917	--	40,800	509	54	17,500
18	III	E	36	40	58,191	46	24,000	8,831	77	8,875	6256	54	17,500
19	IV	F	36	40	29,758	46	24,000	7,881	77	8,875	5620	54	17,500
20	V	G	36	30	32,930	35	28,850	6,147	67	11,500	5051	54	17,500
21	V	G	36	40	31,427	46	24,000	3,182	77	8,875	5996	[illegible]	17,500
22	VII	L	36	40	32,177	58	15,300	11,599	124	3,200	10300	107	4,250
23	VI	G	36	30	27,560	44	26,000	7,890	67	11,500	6643	54	17,500

TABLE XIII. TOWER COMPUTER INVESTIGATION

COMPUTER RUN NUMBER	GUY 1		GUY 2		GUY 3		GUY 4		GUY 5		GUY 6	
	TENSION	BREAKING STRENGTH LBS.	TENSION	BREAKING STRENGTH LBS.	TENSION	BREAKING STRENGTH LBS.	TENSION	BREAKING STRENGTH LBS.	TENSION	BREAKING STRENGTH LBS.	TENSION	BREAKING STRENGTH LBS.
1	2082	1100	8165	10000	7047	10000	6494	10000	4917	10000	3932	10000
2	2047	1100	7933	10000	6832	10000	6298	10000	4730	10000	3835	10000
3	2080	1100	8107	10000	7048	10000	6522	10000	4991	10000	3897	10000
4	1988	1100	7554	10000	[illegible]	10000	5875	10000	4450	10000	3807	10000
5	2779	4500	9189	18000	7804	18000	6731	18000	4754	18000	4208	18000
6	2794	4500	8900	18000	8016	18000	6711	13000	4993	10000	4154	10000
7	3036	4500	9203	23500	8327	23500	7015	18000	5413	13000	4177	10000
8	2515	4500	9073	18000	8130	18000	6632	13000	5139	10000	4228	10000
9	2603	4500	9366	18000	8207	18000	6556	13000	5134	10000	4226	10000
10	2809	4500	9672	18000	7974	18000	6730	13000	5203	10000	4211	10000
11	2399	4500	9822	18000	7885	18000	6694	13000	5210	10000	4219	10000
12	2793	4500	9442	18000	7816	18000	6778	13000	5197	10000	4200	10000
13	2390	4500	9579	18000	7935	18000	6744	13000	5203	10000	4208	10000
14	2199	4500	[illegible]570	18000	7935	18000	6841	13000	4828	10000	----	-----
15	196[illegible]	4500	8303	18000	[illegible]04	18000	5858	13000	4162	10000	----	-----
16	792	4500	4041	18000	3715	18000	2565	13000	2601	100[illegible]0	1647	10000
17	----	----	2251	18000	1900	18000	1394	13000	1405	10000	1061	10000
18	2832	4500	11203	50000	10013	50000	9066	40000	8431	36000	7348	28000
19	3000	4500	8847	23500	9235	23500	7401	18000	6387	13000	4697	10000
20	2284	4500	8553	18000	9058	18000	6838	13000	6840	13000	4661	10000
21	1931	1100	5196	10000	4172	10000	3822	10000	3568	10000	3118	10000
22	2553	4500	9603	18000	9307	18000	6759	13000	6841	13000	4633	10000
23	2480	4500	9076	18000	8715	18000	6392	13000	6475	13000	4459	10000

TABLE XIV. GUY MATERIAL PROPERTIES

GUY MATERIAL	BREAK STRENGTH IN LBS.	DIAMETER	WEIGHT IN LBS PER 100 FT.	TENSILE PSI	BREAK LENGTH IN FT.	STRETCH 20% LOAD	SPECIFIC GRAVITY	MOISTURE ABSORPTION	FLEXIBILITY	WEATHERING (CORROSION)	CONDUCTING	RF BURNING
Manila	11,000	1 1/8	36	9,000	30,600	6%	1.32	60%	Excel	Poor	No	Poor
Nylon	11,000	5/8	10.5	28,000	105,000	22%	1.14	25%	Excel	Fair	No	Poor
Polypro-pylene	11,000	7/8	15.4	18,000	71,500	16%	.90	20%	Excel	Good	No	Poor
Dacron	11,000	5/8	13.5	28,000	81,500	6%	1.38	25%	Excel	Good	No	Poor
Mylar	11,000	3/4	16.7	25,000	66,000	2%	1.35	12%	Excel	Good	No	Fair
Galv. Steel 6 x 7 imp.	11,000	3/8	21	100,000	52,500	.5%	7.7	<.1%	Good	Fair	Yes	Na
Stainless Steel 1 x 19	11,000	5/16	21	143,000	52,000	.5%	7.8	<.1%	Good	Good	Yes	Na
Aluma Weld	11,000	5/16	20.8	143,000	53,000	.5%	7.4	<.1%	Fair	Good	Yes	Na
Glass Rod	11,000	5/16	6.75	143,000	163,000	.60%	2.0	<.1%	Poor	Good	No	No
Glastran	11,000	5/16	5.7	143,000	193,000	.67%	1.9	<.1%	Good	Good	No	No
Nolaro Dacron	12,000	5/8	13.7	30,500	NA	1.8	1.4	<.1%	Excel	Good	No	No

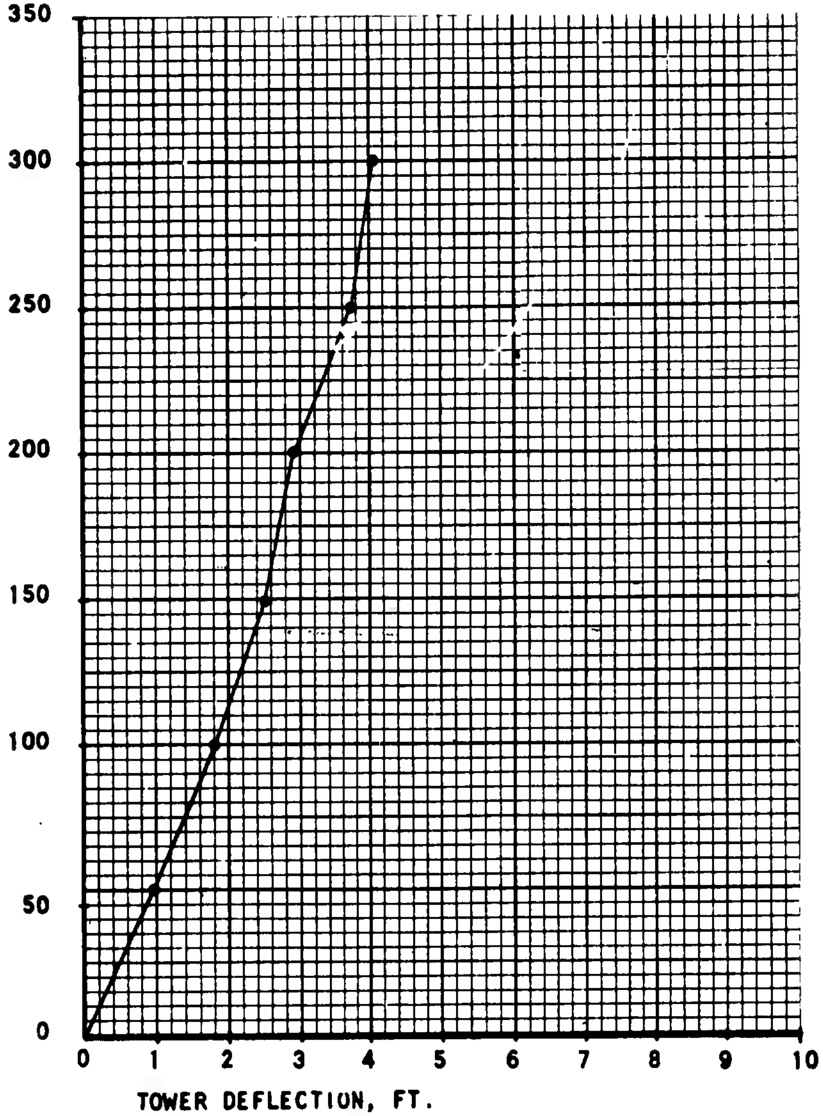


Figure 50. Computer Run #11

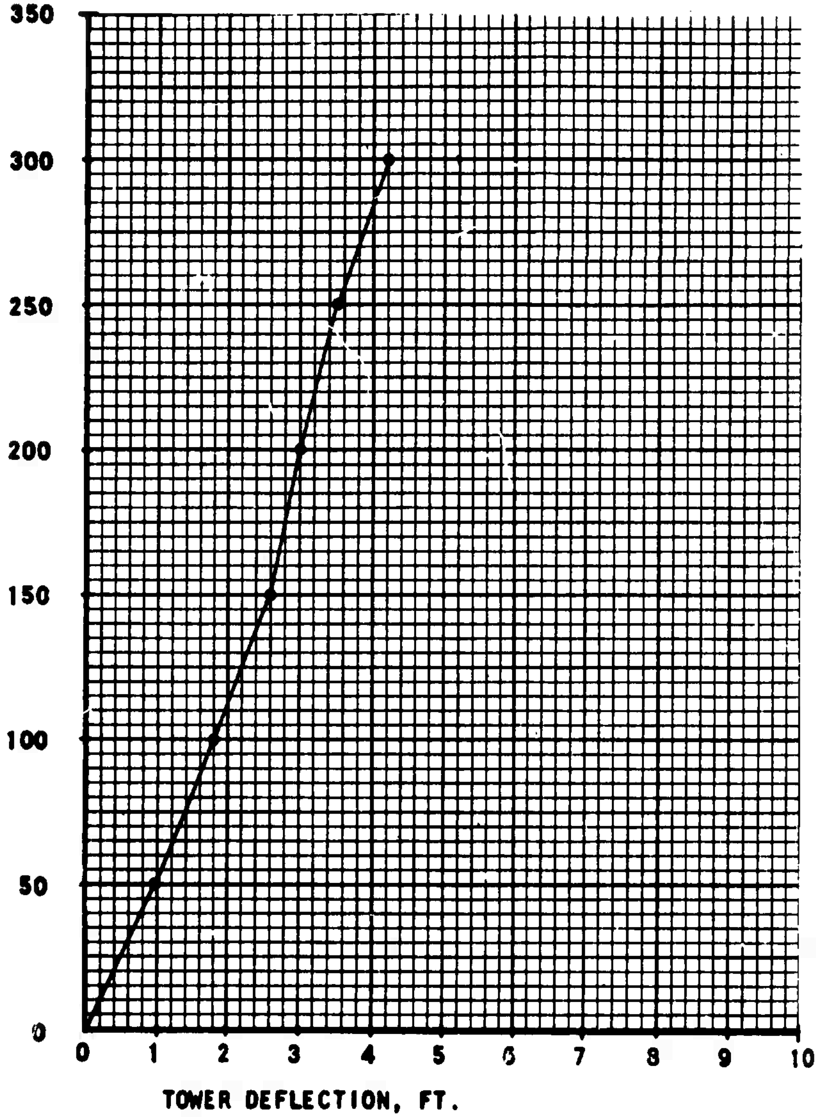


Figure 51. Computer Run #12

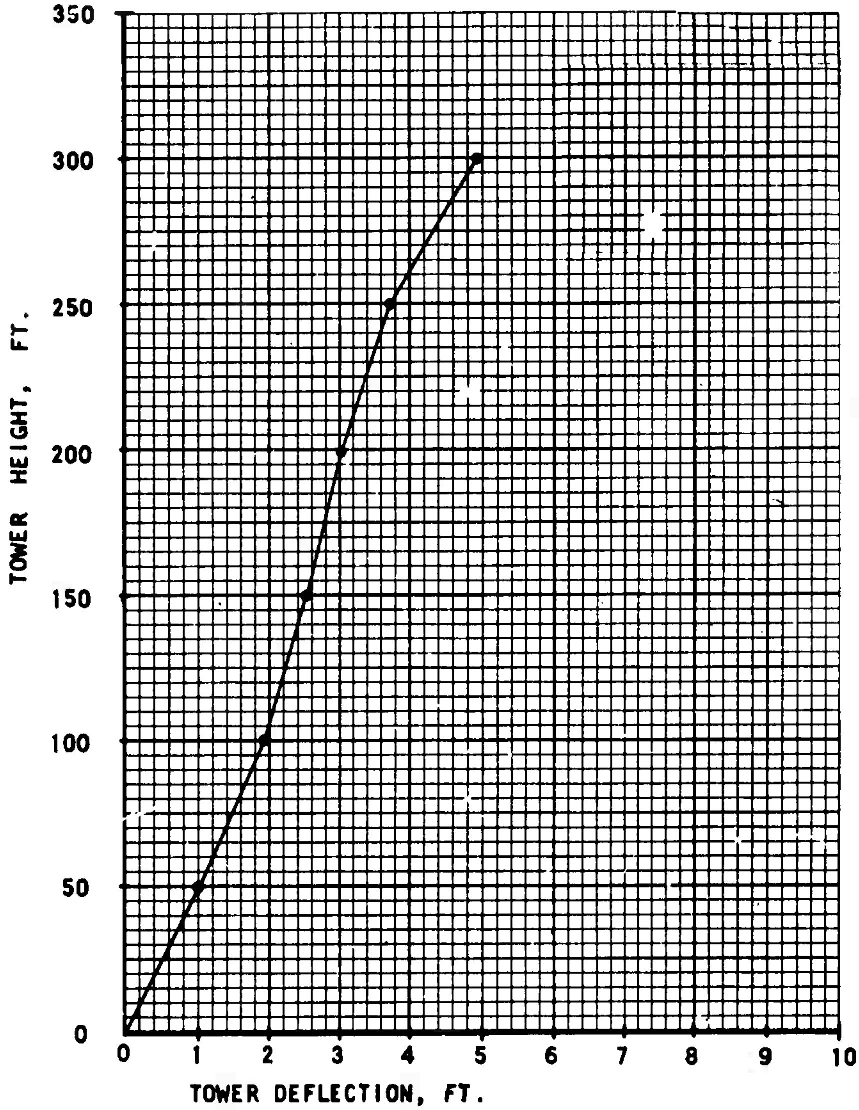


Figure 52. Computer Run #13

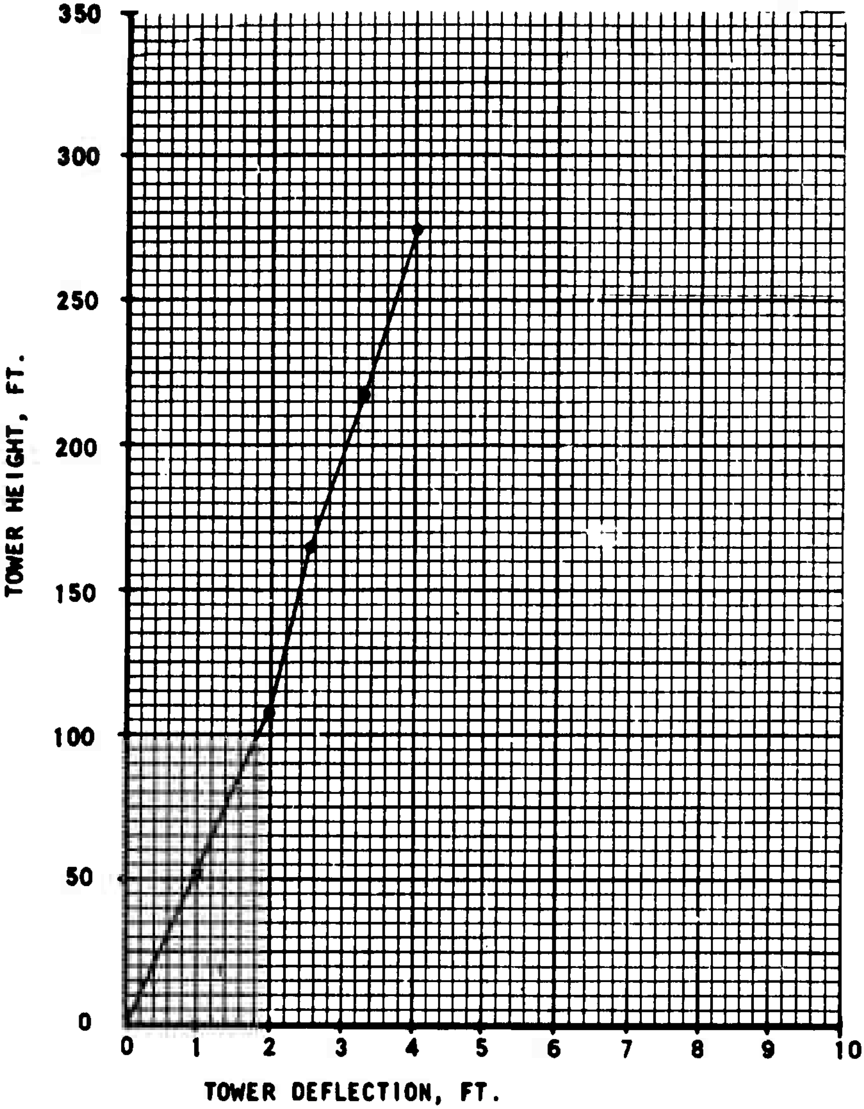


Figure 53. Computer Run #14

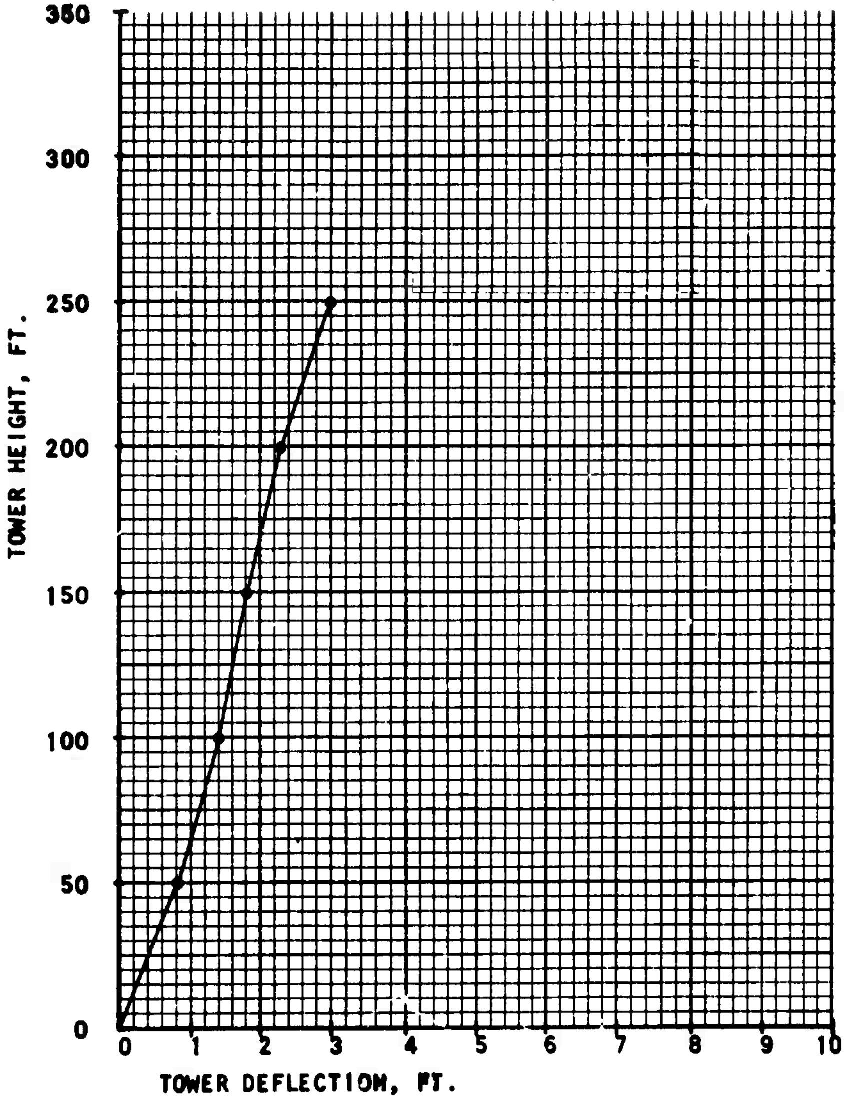


Figure 54. Computer Run #15

the scaffold tower, it is clear that it could be lightened considerably and still remain within acceptable stress levels at the special condition of 70 knot winds and no ice. Figure 55 indicates a minimum of deflection.

(m) Run No. 17

This run was made to determine the safety factors in the structure during erection, with a man positioned at the 300-foot level and the tower guyed up the 250-foot level, leaving the top section cantilevered. A 20-knot wind at 30 feet is assumed with no ice present. As shown in table XIII, the guys have safety factors in the order of five to one. The tower member stresses shown in table XII are at a level which provides a minimum safety factor of six to one. Figure 56 indicates that the man will be subjected to approximately 1.2 feet of horizontal tower displacement at this worst possible condition, and the deflection would be even less if 12 radiators were used instead of the 9 considered here. If normal safety precautions such as the use of a safety belt are employed, the person climbing the tower is relatively safe.

This support structure has been in operation with the standard antenna, and has shown capability of satisfying system requirements. The design principles have been proven through wide usage of similar commercial structures.

Changes recommended in this tower are as follows:

1. Use tower configuration II, table IX

2. Use guy configuration V, table X

3. Provide temporary hinge brackets at base insulator for pivoting lower 30 feet of assembled tower

(2) Tilt-up Tower

The tower shown in figure 63 is an adaptation of the AN/TSA-17 lightweight transportable tower. The AN/TSA-17 tower was designed to operate at a height of 70 feet and to support a transportable hf antenna array. It is erected by means of a falling A-frame 10 feet in height, connected to the 40-foot level of the tower by a lifting cable. By attaching a winch to the top of the A-frame, the tower is pulled into the vertical position and guyed.

To satisfy the present requirements, a similar but larger tower is considered. Like the AN/TSA-17 tower, it consists of 12-foot sections which are further sub-divided into three interchangeable leg assemblies. When stored, the leg assemblies are stacked as shown in figure 63. All fabrication of this tower, as with the scaffold-type tower, is accomplished by epoxy bonding, riveting, and bolting, rather than welding to eliminate localized annealing of the aluminum. 7178-T6 aluminum is the alloy to be used in the analysis because of its high strength properties.

The erection of this tower is accomplished as follows:

(a) Assemble leg assemblies into sections as shown in figure 63.

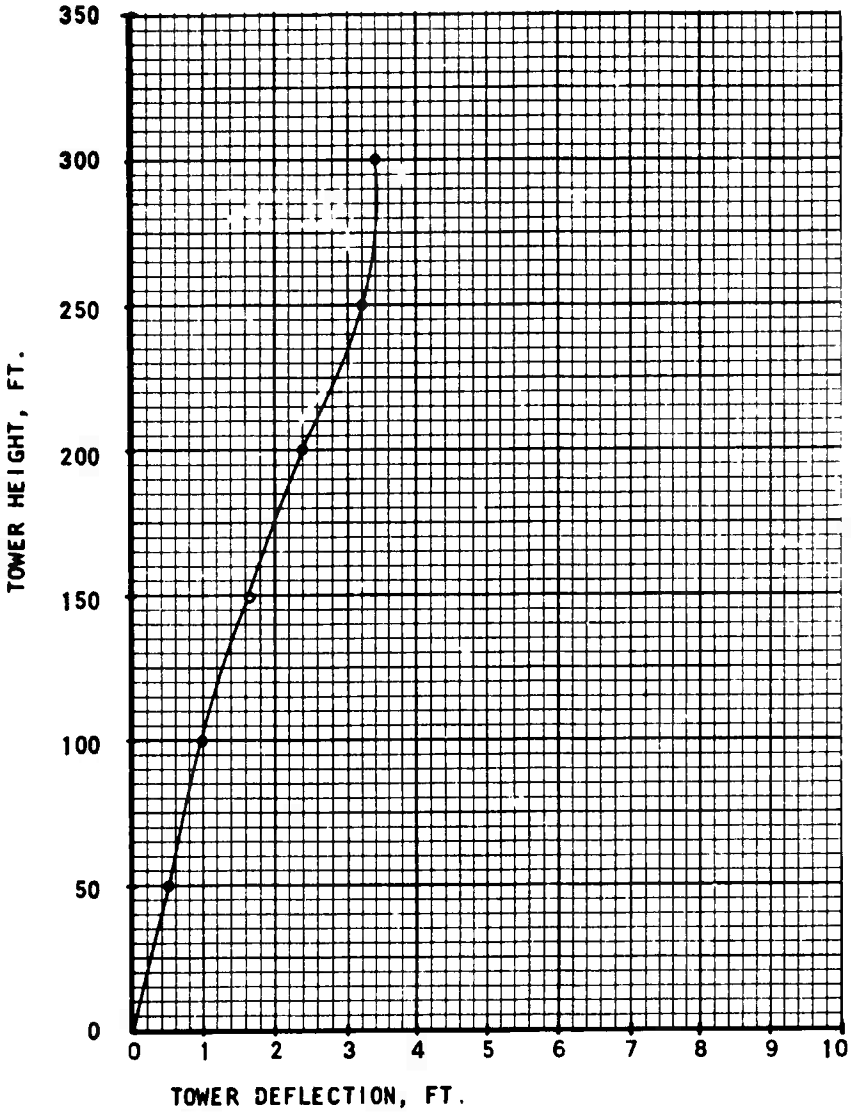


Figure 55. Computer Run #16

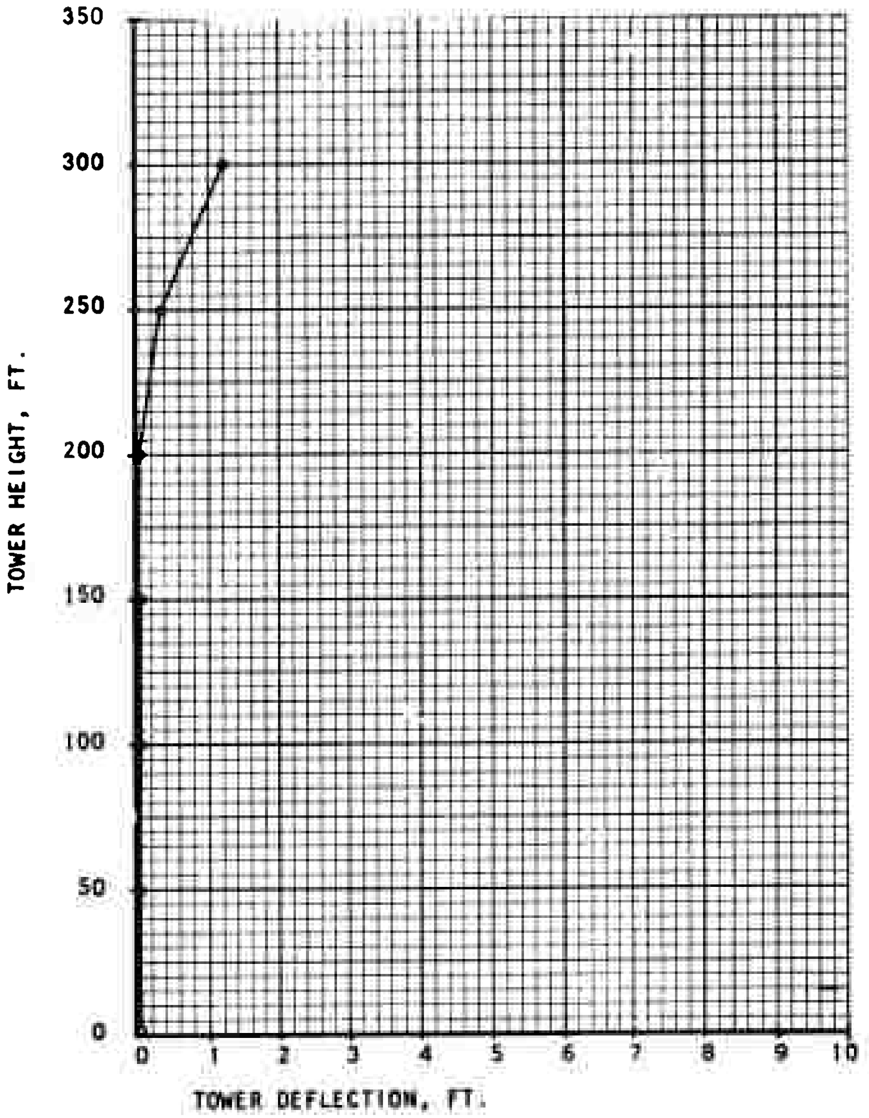


Figure 56. Computer Run #17

(b) Completely assemble sections and guys on the ground, and attach lighting kit.

(c) Attach and tension side guys to their respective anchors.

(d) Attach rear guys to their respective anchors as shown in figure 64.

(e) Attach, starting from the top of the tower, guys 1, 3, and 5 to the top of the falling A-frame as shown in figure 64.

(f) Attach winch to top of A-frame as shown in figure 64.

(g) Winch to vertical position as shown in figure 65.

(h) Attach guys 2, 4, and 6 to their respective anchors, as shown in figure 65.

(i) Remove guys 1, 3, and 5 from A-frame, and attach to their respective anchors.

At all times during this procedure, the tower is stabilized by attached guys and the winch. This method of erection eliminates the requirement of climbing the tower during erection.

Requirements of accessory or additional equipment of this tower configuration include a winch, A-frame, and an additional set of guys for 4-way guying.

The following computer runs were made to optimize this tower configuration.

(a) Run No. 18

This run utilizes tower configuration III and guy configuration E, as shown in tables IX and X. Table XII indicates that the leg members are overstressed considerably for this run. The guys, shown in table XIII, are considerably understressed, with safety factors of five to one on the average. Figure 57 indicates a relatively linear tower displacement, with a maximum displacement of two feet.

(b) Run No. 19

Tower configuration IV and guy configuration F are implemented in this run. As shown in table XII, the leg members of the tower are overstressed, with horizontal and diagonal members within limits. Guy loads, as shown in figure 13, remain overly safe, but to a lesser degree than the previous run. Figure 58 indicates that the tower at the top section departs from a linear configuration.

(c) Run No. 20

Tower configuration V and guy configuration G are used in this run. Table XII indicates that the leg members remain somewhat overstressed,

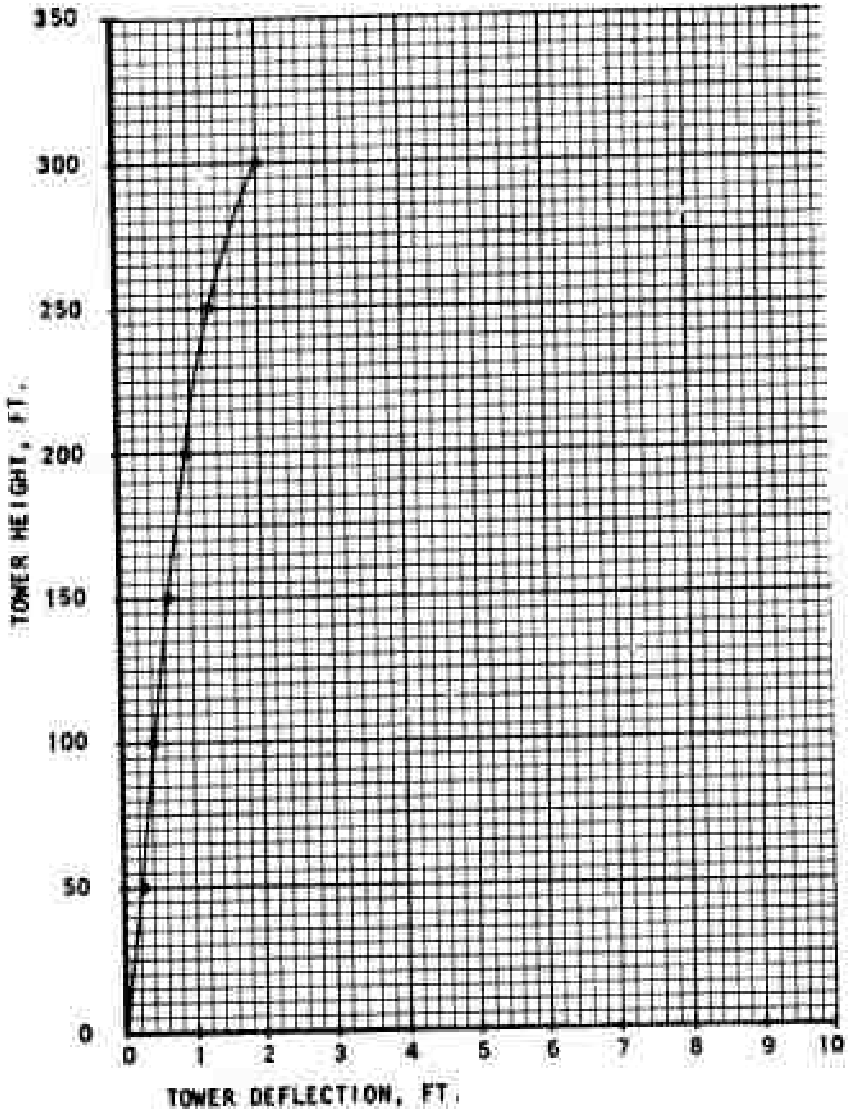


Figure 57. Computer Run #18

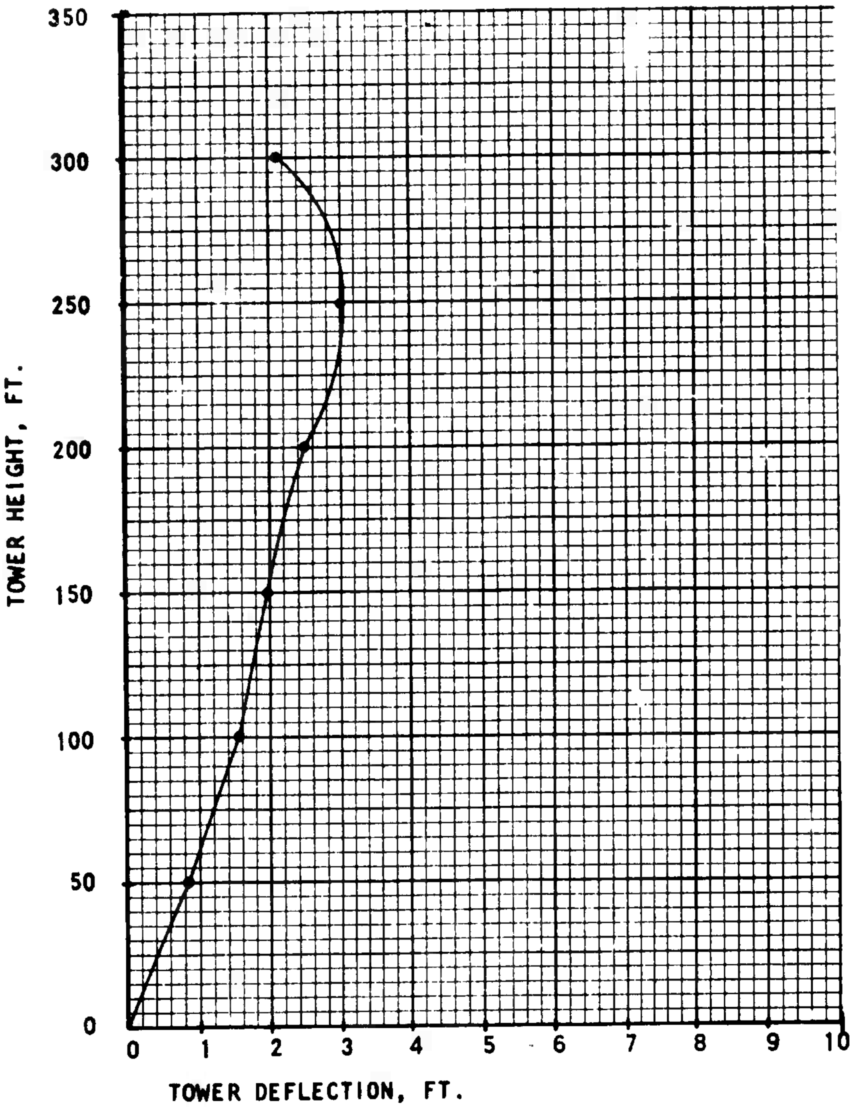


Figure 58. Computer Run #19

with diagonal and horizontal members well within acceptable limits. The guys are loaded to near optimum values of a safety factor ot two to one, as shown in table XIII. Figure 59 indicates a linear deflection plot of the tower under load.

(d) Run No. 21

Tower configuration V and guy configuration G are again used in this run, however with different values of h' and different guy sizes. Tables XII and XIII indicate that the leg members are overstressed, and that the top guy level is overloaded. Figure 60 indicates a relatively linear tower deflection with a maximum deflection of about 5.5 feet.

(e) Run No. 22

Tower configuration VII and guy configuration L result in tower members being overstressed, as shown in table XII. The guys, as shown in table XIII, are within load limits. Excessive tower deflection results from these configurations, as indicated in figure 61.

(f) Run No. 23

Tower configuration VI and guy configuration G are used in this run. It should be noted that this tower configuration is similar to that used in configuration II for the scaffold-type tower in run No. 10. Table XII indicates that the leg stresses are nearly optimum (safety factor of 1.9 to 1) with diagonal and horizontal members within acceptable limits. All guys are at values of safety factors nearly 2 to 1 as shown in table XIII. A maximum tower deflection of approximately 5.8 feet, together with linear tower displacement is shown in figure 62, indicating that minimum bending moments are being applied to the structure.

A brief analysis of erection stresses is shown in appendix III; the factor of safety during this operation is 2.4 to 1.

(3) Inflatable Tower, Goodyear Type

The following inflatable support structure is proposed by Goodyear Aerospace Corporation. They were consulted regarding this study, and their concept merits consideration for this application.

Goodyear Aerospace Corporation's concept of a 300-foot-high inflatable antenna mast features an automatically erectable inflatable tower consisting of a tapered tubular envelope of a high-strength rubberized fabric that is pressurized to achieve a rigid tower structure. Guy cables are used at appropriate levels, as with a conventional tower, to resist wind loads and prevent buckling or excessive deflection. The strucural integrity of the tower is maintained by the pressurization system, which provides adequate material tension to offset compression loading due to the wind load moments, the vertical components of the guy cable loads, and the weight of the fabric and cable. Thus, buckling of the mast is prevented.

The erection of an actual 50-foot high automatically erectable tower takes less than 8 minutes. A 300-foot tower utilizing the same basic concept will be possible to erect or retract and repack efficiently in 2 to 5 hours, using not more than a 10-man crew.

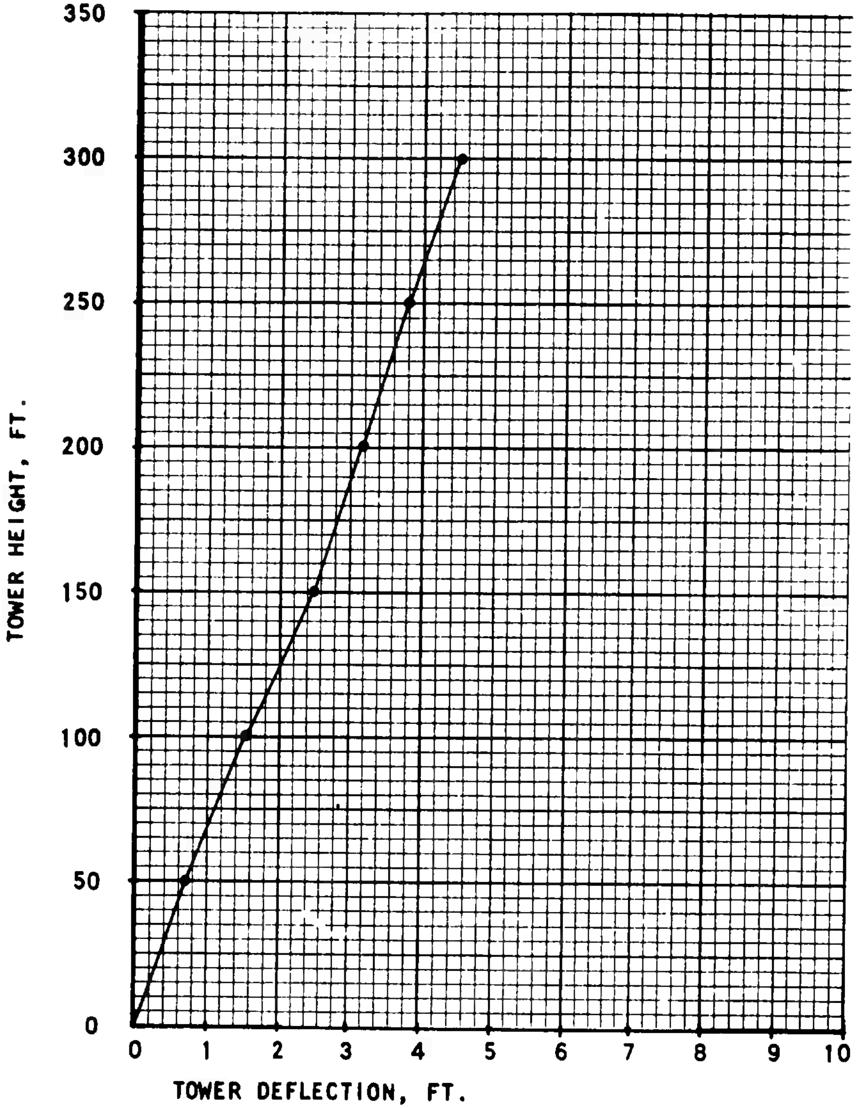


Figure 59. Computer Run #20

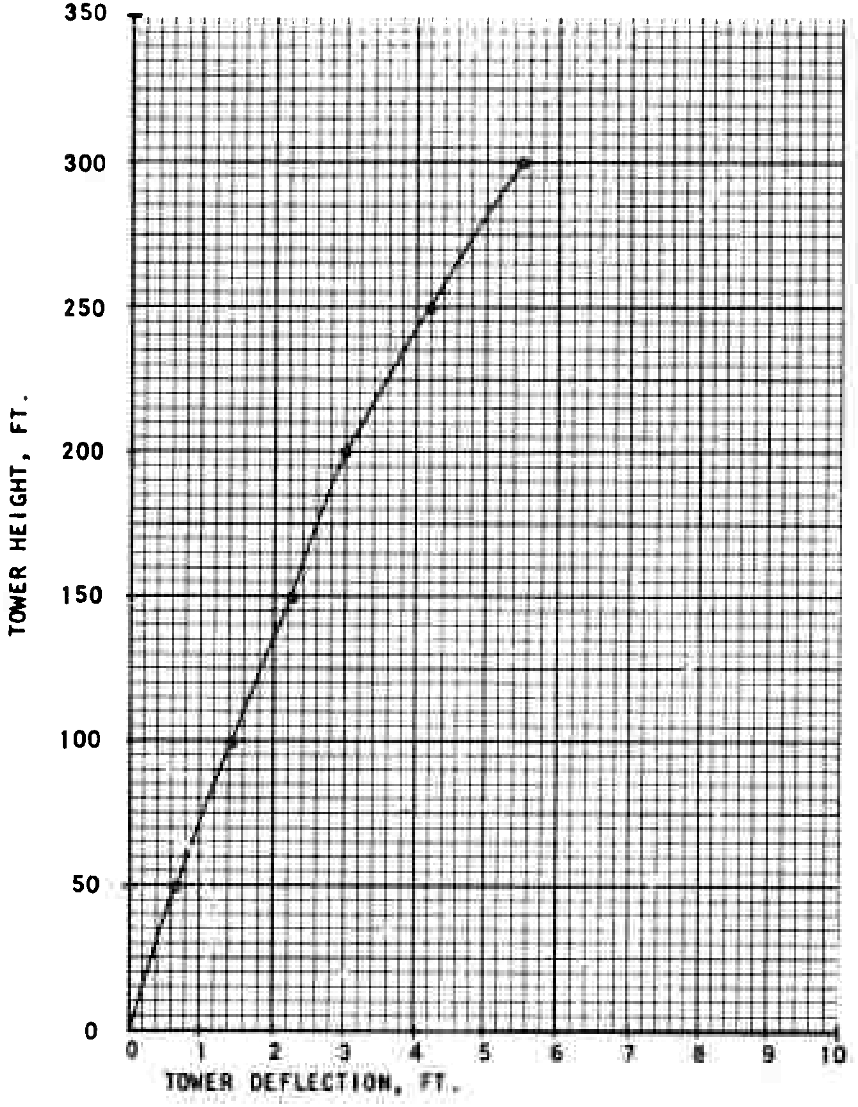


Figure 60. Computer Run #21

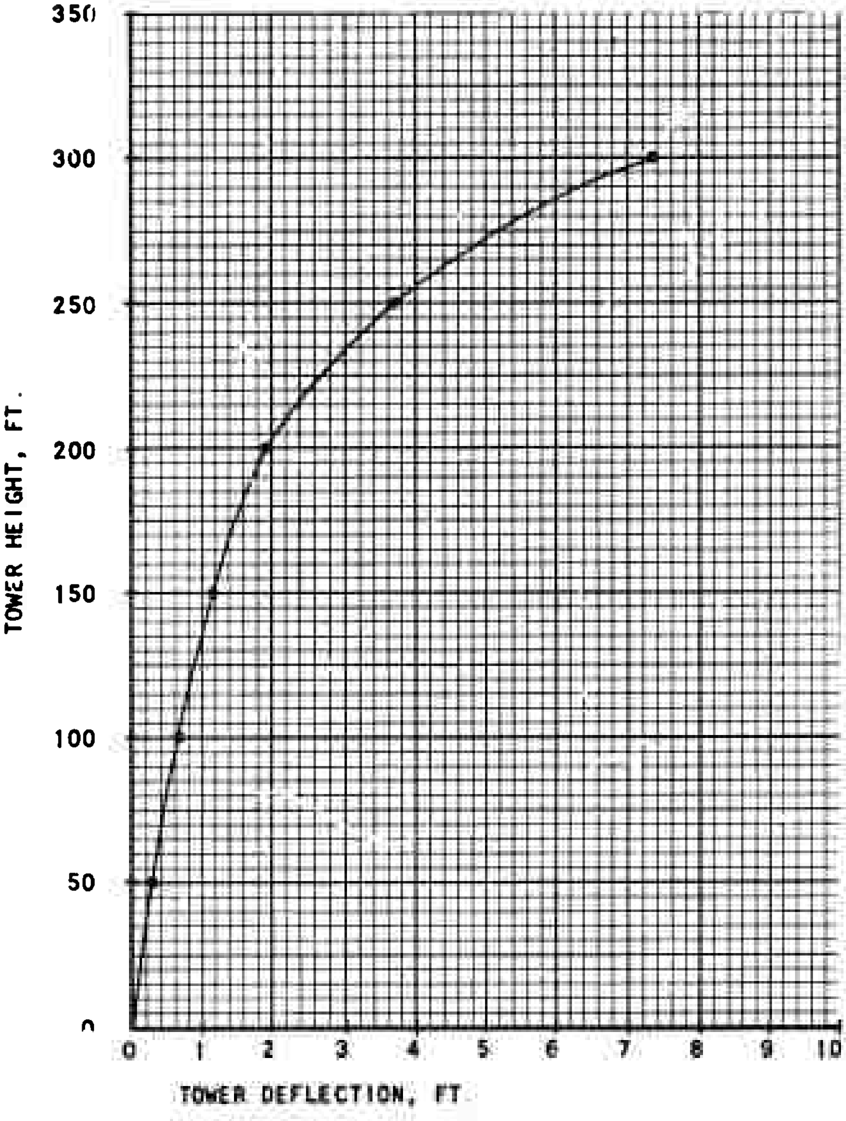


Figure 61. Computer Run #22

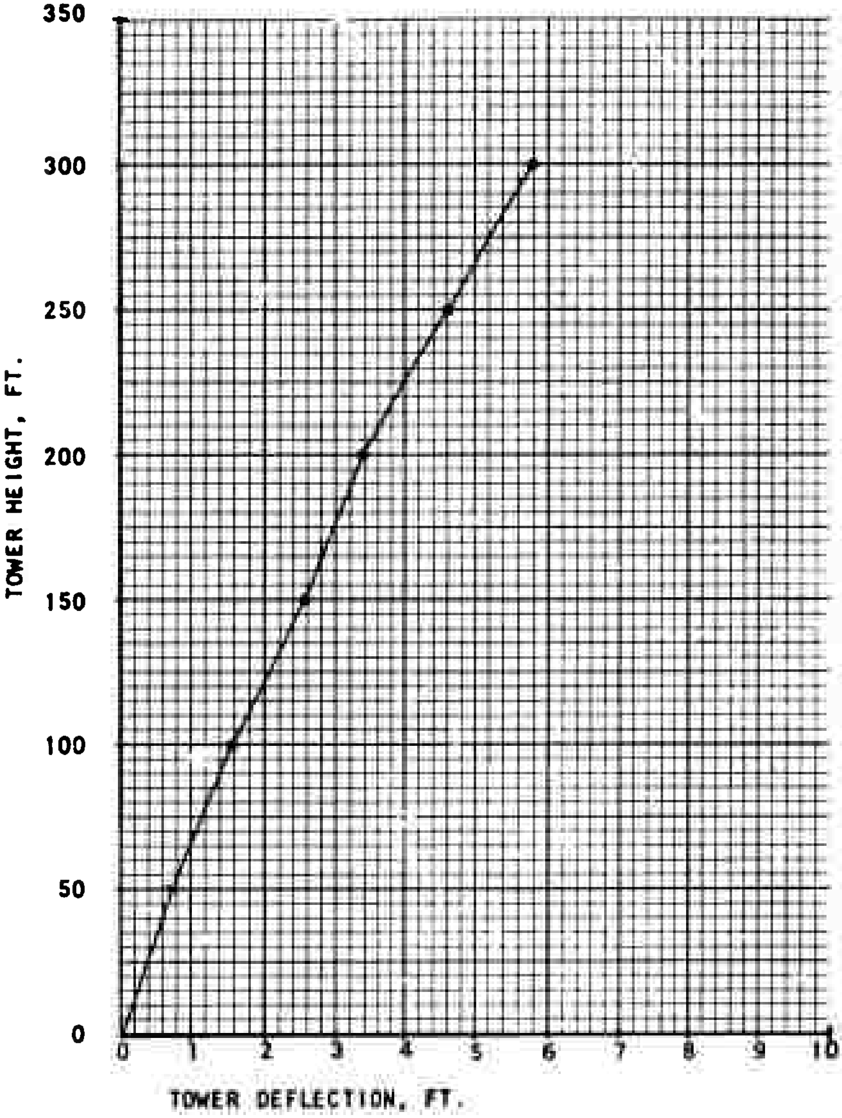


Figure 62. Computer Run #23

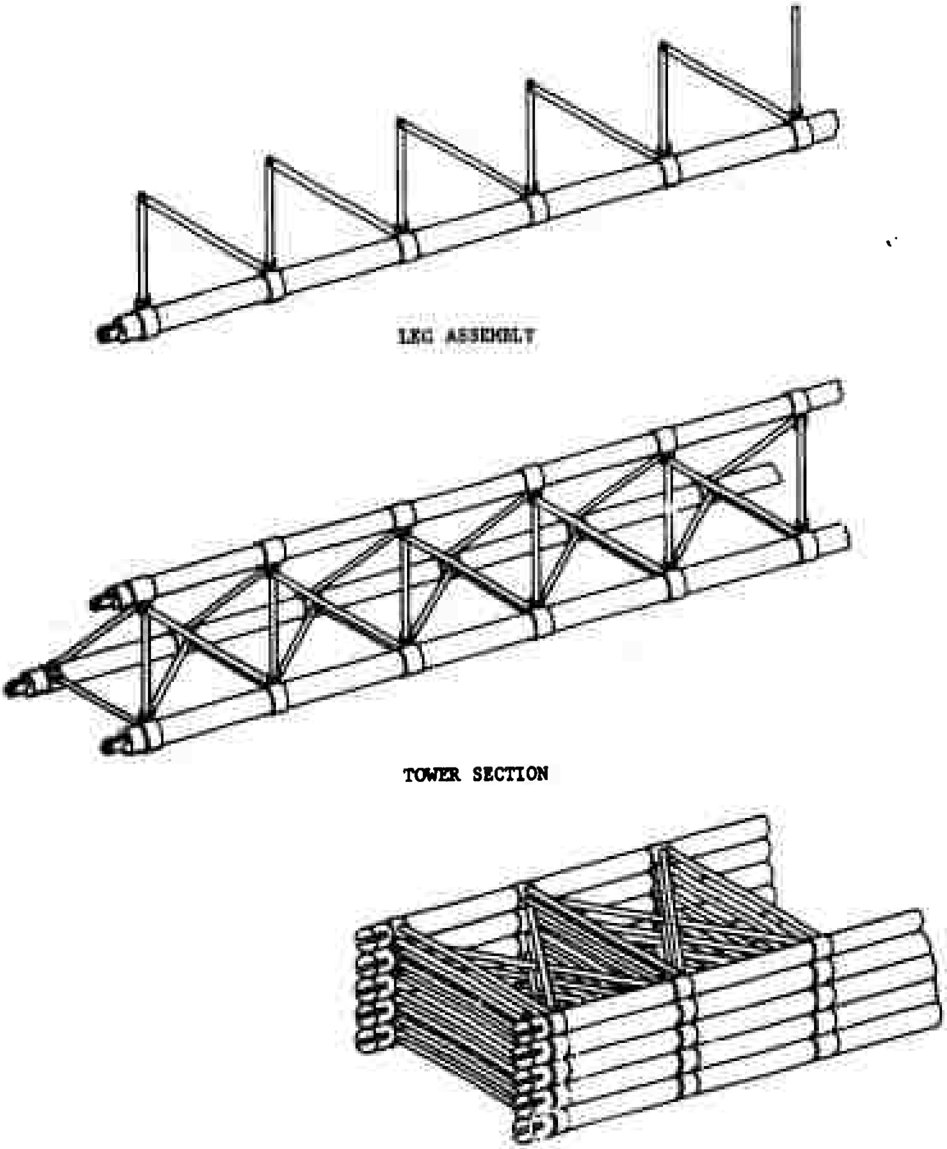


Figure 63. Packaged Tower

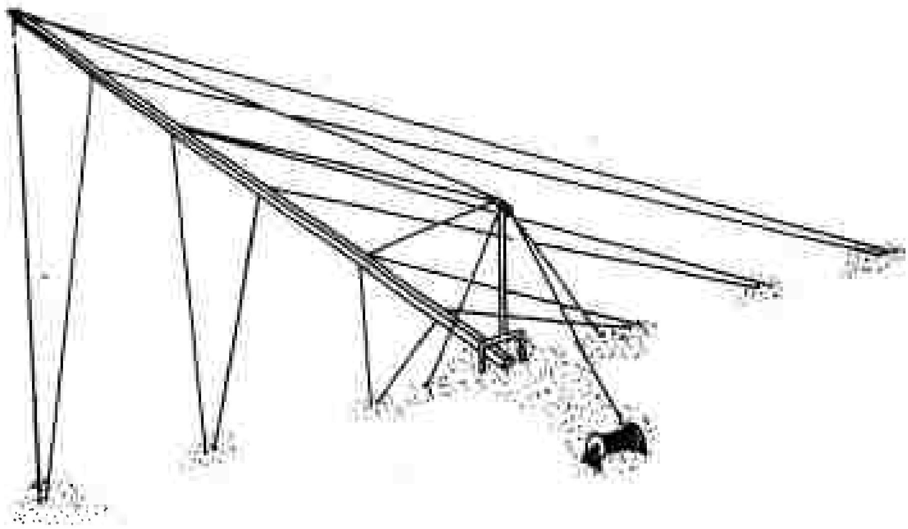


Figure 64. Tilt-Up Tower, Ready for Erection

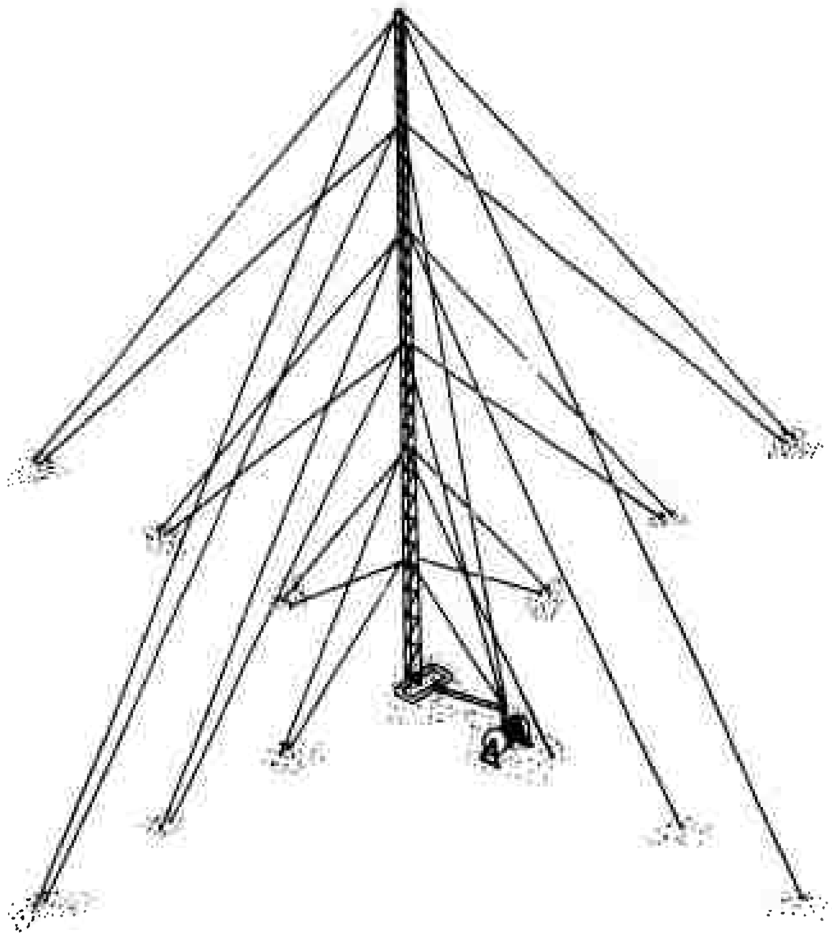


Figure 65. Erected Tilt-Up Tower

The most time consuming task during erection is the installation of ground anchors. This task can be expedited by additional sets of anchor installation equipment.

As the tower is inflated or deflated, it automatically extends upward or retracts into the support base, respectively. The tower will remain erect and rigid at all heights up to 300 feet as it is extended or retracted. The tower is automatically extended by the action of air pressure as it is raised or retracted by means of a reel in the base.

The guy cables, the upper ends of which are permanently attached externally on the tower, are also reeled in with the tower. Thus, when the tower is inflated, the guy cables are automatically deployed and it is merely necessary to attach the lower ends to ground anchors and pretension them. As each level of guy lines is exposed, the guys are attached to the ground anchors and tensioned. Thus each level of guy lines supports the tower as it is extended to its full height.

The top-loading antenna array can be deployed and retracted in the same manner as that for the guy lines. The erection and retraction are controlled by a relatively lightweight power pack, whose basic components consist of a blower, speed reducer, reel, brake, and motor or engine.

A preliminary structural analysis indicates that 12-guy levels would probably be optimum for a tower tapered from 5 to 2 feet in diameter. With an internal pressure of about 15 psi, this mast will be capable of surviving a 70-knot wind. Past analyses have been based on the assumption that radial ice does not occur simultaneously with the 70-knot wind, because lower velocity winds would crack and break the ice off before a 70-knot wind would occur.

In addition, the forming of ice on the inflatable mast itself may not occur. Exposure tests during the past winter on a 50-foot tower indicate that the fabric can be treated and the tower pressure varied so that the formation of ice can be prevented. A considerable weight penalty would result if the tower were designed to take the combination of ice and full wind loads.

This tower is designed for a midheight (150 foot) operation without modification. It would be erected in the usual manner. The top loading radiators would then extend 150 feet out from the top of the tower and form a somewhat larger angle with the vertical than it would when fully erected. A conductive ring would be used at midheight to protect the fabric from abrasion and to ensure electrical continuity from the tower into the top-loading conductors.

The tower can withstand a -65° to +160° F ambient temperature in the packed or erected state, but it cannot be deployed or retracted at -65° F. The limiting erection and retraction temperature may be approximately -40° F.

The other environmental conditions specified, such as humidity, barometric pressure, salt atmosphere, sand and dust, insects, and fungi, should present no problems in the use of an inflatable antenna tower.

Experience has indicated that with periodic maintenance procedures, an inflatable antenna tower of the concept suggested above will have a 2-year service life, including 15 to 20 erections and retractions during this period.

The requirement for packing size does not appear to be difficult to meet. However, the 3000 pound weight goal presents somewhat of a problem. Previous weight estimates for a 300-foot inflatable antenna tower indicate that the whole system will weigh approximately 4100 pounds. However, about 1500 pounds of this is auxiliary equipment. A 2-package transport system will weight about 2600 pounds. Spring steel tapes may be considered for reinforcement between plies to improve the strength-to-weight ratio.

To make the inflatable tower electrically conductive so that it can be used as a radiating element, at least four approaches are feasible:

(a) Use a flexible silver loaded latex paint

(b) Laminate aluminum foil to the tower fabric

(c) Laminate fine mesh wire screen to the tower fabric

(d) Incorporate a conductive wire in the tower.

The antenna array at the top of the tower will be connected electrically to the conductive surface of the tower.

For previous inflatable tower projects, tower lighting in accordance with FAA regulations has been considered, and does not appear to be a major problem.

(4) Inflatable Tower, Birdair Type

The inflatable tower developed by Birdair Structures differs in concept from the Goodyear tower. It differs in configuration, pressurization system, and method of erection.

The proposed tower support consists of a conical coated fabric envelope 3 feet in diameter at the top end, 22 feet diameter at the base, and 300 feet high, as shown in figure 66. Preliminary calculations indicate that the envelope material required for the tower would be a 2-ply neoprene coated Dacron fabric having a total weight of approximately 70 ounces per square yard and a strip tensile strength of 1000 pounds per inch in the warp and filling directions. The use of such a material would result in a completed tower weighing approximately 5000 pounds with a packaged volume of approximately 200 cubic feet. To improve the weathering and general abrasion resistance of the material it is anticipated that the exterior surface of the tower would be given two coats of Hypalon paint.

For normal everyday operations (winds under 45 knots), calculations indicate that an inflation pressure of 1.5 psi can be used. During initial erection, and for higher wind conditions, the pressure would be increased to 3 psi. The tower would be anchored to the ground at approximately 3-foot spacing around the base; 24 anchors would be required. The load per anchor at the base would be approximately 7000 pounds. For stability of the tower under wind loading, the tower would be guyed at 40-, 90-, 150-, and 200-foot positions from the top of the tower. The top cap of the tower would be guyed by the antenna radials. Except for the 10 top radials, all guy levels would consist of a 4-guy system with guys spaced 90° apart in azimuth.

Based on present known requirements, it is anticipated that a 3-blower pressurization package would be used. One low pressure, (5-6 inches H_2O),

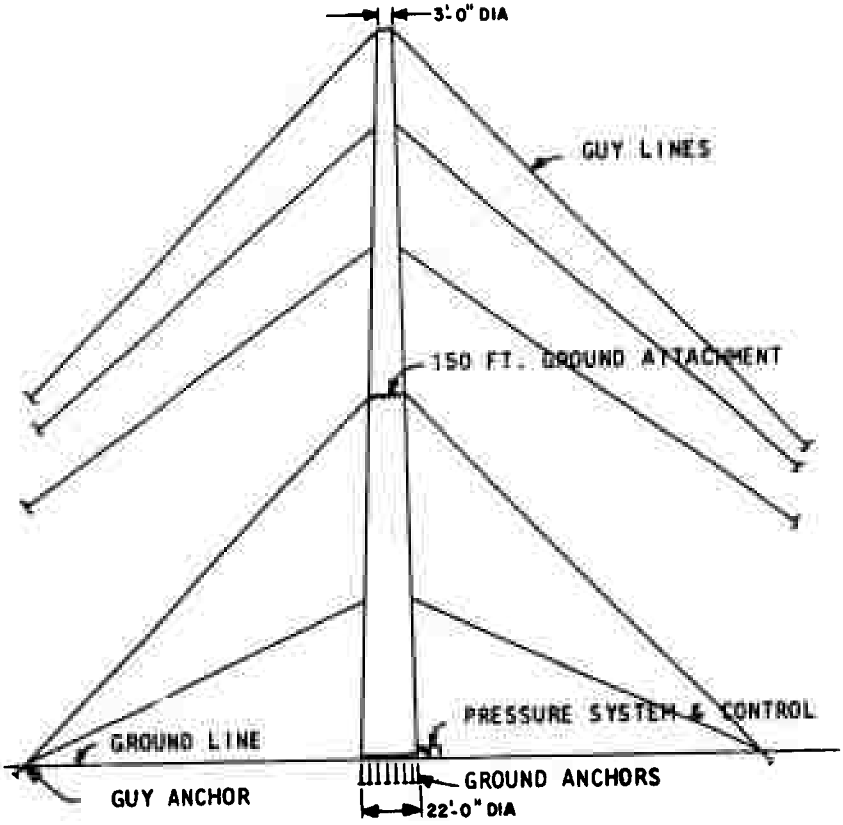


Figure 66. 300 Ft. Configuration

high volume blower would be used to initially fill the volume of the envelope with air. A second intermediate pressure (1.5 psi), lower volume compressor would be used to pressurize the tower for winds up to 45 K. A third high pressure (3 psi), low volume compressor would be used to provide sufficient pressure to erect the tower and to pressurize the tower for winds up to 70 K. All blowers would be provided with manual switches for operation as desired. In addition, the 1.5 psi and the 3 psi compressors could be automatically operated intermittently by pressure switch control to maintain the pressure in the tower between preset level limits. The blowers would each be arranged to discharge into a plenum through a check valve to prevent reverse flow of air through any blower that is not operating. The blower and control system would be contained in a weather tight housing and air would be ducted from the plenum to the tower envelope thru a flexible duct. To prevent overpressurization of the tower due to a sudden temperature buildup, a pressure relief valve would be located in the blower plenum. It is estimated that the maximum compressor power requirement would be 10 horsepower; the normal operational requirement would be approximately 2 HP. All blowers would be of the centrifugal compressor type.

For operation at a height of 150 feet, a set of auxiliary anchor attachment points would be located at mid height on the tower. The lower section of the tower envelope would be folded or rolled to the intermediate position and placed on the base position, as shown in figure 67. Twelve anchors on a 12-foot 6-inch base circle would be used to anchor the tower at the reduced height position.

The erection of the tower would be accomplished in the following sequence:

(a) The base location and guy positions of the tower would be determined and anchors would be placed as required.

(b) The tower envelope would be unrolled or unfolded with the base in position and the remainder of the tower placed in a radial line located downwind from the base position with respect to anticipated, existing, or prevailing wind.

(c) Attach the base of the tower to the ground anchors with the pressure connection on the upwind side.

(d) Locate the pressure package on the upwind side of the base and attach the duct to the tower envelope.

NOTE

The remainder of the installation should only be attempted under relatively calm wind conditions (under 15 mph).

(e) Operate the low pressure blower to inflate the envelope while it is laying on the ground.

(f) Turn on the high pressure blower (3 psi) and begin pressurizing the tower envelope. As the pressure builds up in the envelope, the tower will tend to raise itself using the base attachment as a pivot point. However, due to the long length and weight of the tower it will buckle midway along its length and erect itself in two stages. In the first stage the lower half will raise itself with the upper half folded down such that the top cap will be pointed toward the ground forming

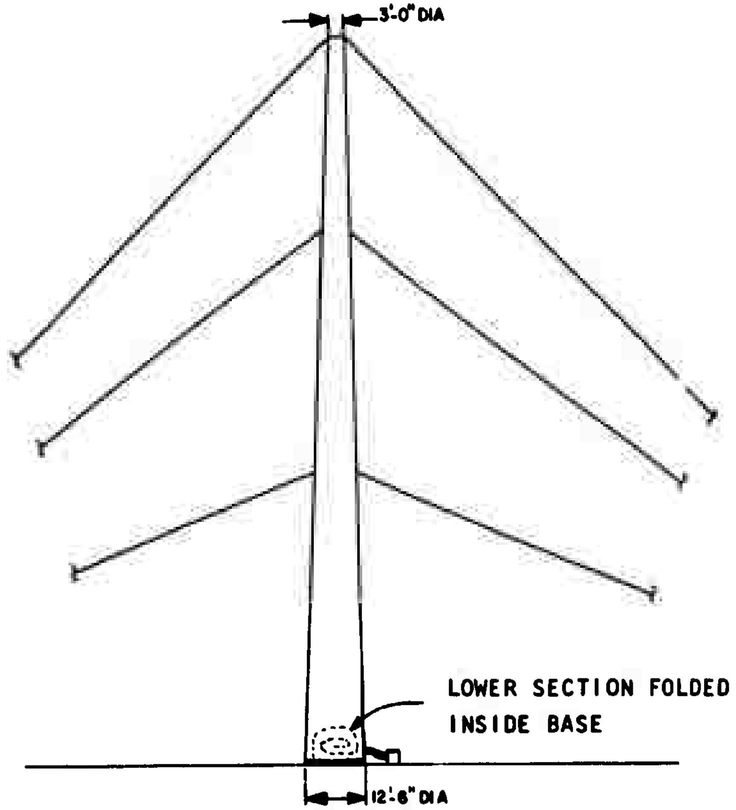


Figure 67. 150 Ft. Configuration

a "knee" in the tower. Secure the lower and mid guy lines. In the second stage the upper half of the tower will raise itself pivoting about the "knee" in the tower envelope.

(g) After the tower is completely erected secure all remaining guy lines.

(h) Turn on the normal operating (1.5 psi) blower for automatic operation and turn off the high pressure blower.

To control the inflation to a greater extent, consideration would be given to compartmenting the tower along its length into numerous sections with spherical bulkheads so that a controlled sequential inflation along the length of the tower could be achieved.

Removal of the tower would be accomplished in the following (simplified) sequence.

(a) Remove the upper three sets of guy lines retaining the mid and lower sets.

(b) Gradually reduce the tower pressure letting the upper section of the tower fold down alongside the lower section reforming the "knee" at the mid height as in the erection.

(c) Gradually reduce the tower pressure further letting the remainder of the tower gradually settle to the ground.

(d) Evacuate all air from the tower envelope and refold or roll the envelope into its transport container.

For ease of handling and erection, consideration would be given to fabricating the tower in 2 to 6 sections. The sections would be joined in the field by quick connect coupling fasteners.

It is pointed out that during erection and removal of the tower all tower motion will be gradual and controllable, thus sudden motions or possible impacts are avoided. Further it would be unnecessary for personnel to climb the tower at any time during the installation or removal.

Specification comments on the Birdair inflatable tower are as follows:

(a) The tower in the guyed condition and pressurized to 3 psi would withstand steady winds of 70 knots.

(b) Preliminary calculations indicate that the tower would withstand the specified icing load if guyed and pressurized to 3 psi. Since the exterior of the tower is essentially smooth, ice would not tend to accumulate.

(c) The specified temperature range of -65° F to 160° F would necessitate the use of a specially compounded low temperature neoprene in the tower envelope material. All other equipment could be selected to meet this requirement. Installation of the tower at -65° F would be extremely difficult due to the stiffness of

the material, although no cracking or other damage would be anticipated. Further testing with the actual tower material would be required in order to evaluate the lowest practical temperature extreme for installation or removal of the tower.

(d) No adverse effect from 100 percent humidity, barmetric pressure differential of 28.50 to 30.50 in. hg., salt atmosphere, sand and dust, and insects and fungi.

(e) With periodic maintenance, such as repainting at 2 year intervals, the tower should have a service life of 6 to 10 years with 50 to 100 erections.

(f) Preliminary calculations indicate that the weight of an inflatable tower would be approximately 5000 pounds.

(g) Calculations indicate a package volume of approximately 200 cu. ft. thus packaging into a 7- by 8- by 12-foot container should pose no particular problem.

(h) Ten men should be able to install the inflatable tower in 4 hours.

(i) No special skills would be required to install the inflatable tower and the necessity of climbing the structure would be eliminated.

(j) There would be essentially no maintenance procedures required while the tower is inflated.

(k) The top cap of the tower would contain sufficient rigid components to support the aircraft warning lights, antenna radials, guys and other required equipment.

(5) Telescoping Towers

Telescoping towers have been built and designed by various manufacturers for heights up to 200 feet. The commonly used method of construction in these towers is a series of nested triangular or rectangular sections that are stored within one another.

The conventional method of erection involves cranking by hand or motor-driven winch and cable assembly which raises the nested sections in sequence. The larger sections are extended first and mechanically locked in place when each successive section is locked in place. Guys are attached prior to erection, and are attached to anchors as the tower is erected.

A telescoping tower with an erected height of 300 feet has been developed by Andrew Tower Corporation of Ft. Worth, Texas. This tower has a rectangular cross section, and is constructed of 6061T-6 aluminum angle legs, and tubular bracing members. The overall length of this tower is approximately 44 feet, with a system weight of 12,100 pounds, including its transporting trailer, winch, and accessory equipment. A 5-kw generator is required to power the winch mechanism. This tower is obviously not suited to a highly tactical application, due to its size and weight. The weight of the tower structure portion of this system is about

5000 pounds. This concept is designed for commercial applications where the weight, size, and transportation facilities are available.

The high weight and large size requirements of the telescoping-type tower is due primarily to the overlap necessary between sections, and that the loading that dictates the minimum section properties results in the lower sections being oversized to accommodate the nesting feature.

From the above considerations, the telescoping-type tower was judged to be not applicable for this application.

(6) Launcher Type Towers

Several firms are at present manufacturing launcher towers, in heights ranging from 30 to 150 feet. This type of tower utilizes a base frame in which sections are placed and raised. When a section has been raised to the height of the launcher base, it is secured temporarily, and another section is inserted under the previous section. This process is repeated until the entire tower has been erected.

Many configurations of tower sections may be raised by this method; tubular, the scaffold snap-out tower, and the knock-down tower previously discussed in paragraph (2), to name a few.

The launcher frame would consist of a frame with guides to support the tower section being lifted, a winch and cable assembly to provide an axial lifting free on the tower section, and a locking mechanism to hold the hoisted tower into position. After the tower is completely erected, the frame would be detached and set aside. A desirable feature of the frame would be that it disassemble into a minimal volume for optimum storage purposes. A power tool used in installation of anchors could be adapted to drive the winch of the launcher frame.

This concept could be packaged within the limits of standard military vehicles, requiring only the additional weight and volume of the launching frame in addition to the standard antenna. Another advantage of this concept is that climbing the tower is not required.

A disadvantage of this concept, which becomes critical at the tower heights considered here, is paying out guy cables as each successive tower section is raised. Each guy must be slacked off enough to allow the tower to be raised the height of one section (12 feet) and with increased height, this becomes more difficult. Dielectric guy cables such as Glastran will not work successfully with guy adjustor devices as will aircraft cable guys. If any normal wind loading (up to 20 knots at 30 feet) is present, stability of the tower is marginal. Special devices such as slip clutches set at pre-determined tensions are costly, difficult to maintain, and not reliable. No adequate solution to this problem was discovered, therefore the launcher type tower could not be recommended for this application.

Another structural concept to which the above deficiency applies would be a STEM (Storable Tubular Extension Member) design similar to that used as space-boom antennas. Masts of this type have been experimented with at heights in the order of 40 feet. Other difficulties with this system would include excessive weight, high cost, reliability, and the attachment of guys and radiators. The STEM principle cannot be recommended as applicable to this antenna system.

(7) Dynamic Lifting Balloons

Goodyear Aircraft Corporation was consulted regarding dynamic lifting balloon supported antennas and their Vee-Balloon concept is discussed.

In general, the Vee-Balloon antenna support concept offers a system for serious comparison with other antenna concepts. New high-strength, low-gas permeability fabrics, coupled with an improved aerodynamically designed balloon configuration, have resulted in an extremely stable, high lift balloon system ideally suited to support applications. The integration of this system into an air transportable operation could provide a very effective solution to the problem of substituting a wire antenna for a conventional tower-supported antenna.

The Vee-Balloon is probably one of the best dynamic lift balloons, since it develops a high L/D (lift-to-drag) ratio without stability problems. The Vee-Balloon obtains directional stability with small vertical tail surfaces and its lift and drag characteristics show values of over three. For equal volume, its diameter or height and length is less than that of other types of kite balloons, considerably easing handling and launching operations. The greater lateral width at the tail is well compensated for by improved handling and flying qualities.

A tri-tether guy system is a possible configuration together with the single-tethered system. The tri-tether system can be employed where a more stable antenna is required. A tri-tether on the balloon is used on a quarter-wave antenna to maintain the antenna as vertical as possible. This system is also required for a balloon supported antenna with less than a quarter-wave radiator to provide a top loading for the antenna. If a full quarter-wave antenna is not used, top loaded antenna heights of 1500 to 2000 feet with the top loading extending about 1000 feet to 500 feet, respectively, may be a reasonable estimate.

It is important to keep the antenna portion of the guy wires as taut as possible. To do so in a no-wind condition, a Vee-Balloon with excess lift is recommended. When under a wind load, the Vee-Balloon develops considerable lift; therefore, angles of attack of 6, 8, and 10 degrees have been examined for typical wind velocities. Tensions developed by the balloon range in the vicinity of the breaking strength of any individual tether cable, but since the resultant angle of the lift and drag of the Vee-Balloon remains inside the vertex of the tether cable juncture, all the cables share the load, but to different degrees.

Although the weight and wind loads on the guy cables cause them to sag, the high lift of the Vee-Balloon tends to hold the guy cable to ground angle to 45 degrees, as desired. A conventionally shaped ballon of the same size yields only about one-half this angle. Since the straighter or larger the angle maintained provides the more stationary or stable antenna, the Vee-Balloon is superior for the proposed application. This adds another advantage to the already mentioned stable flight characteristics of this vehicle and its simpler ground handling.

The Vee-Balloon configuration consists of two aerodynamically shaped bodies, intersecting at an angle of 40 degrees and joined at the nose. At the aft part, the two bodies are joined by an inflated horizontal tail surface that provides longitudinal stability. Two small inflated vertical surfaces located under each body provided directional stability.

The size of the balloon depends on the lifting capacity of the selected gas at the prescribed altitude and temperature conditions, on the weight that will be carried, and on the balloon's own weight. A cursory weight estimate on the complete balloon-supported antenna system shows that a quarter-wave radiator system can be provided within the specified weight limitations of 3000 lb.

Several items of ground equipment would be required as part of the transportable Vee-Balloon packages. These would include a winch, ground anchors, a ground cloth, and helium bottles or hydrogen generation equipment.

A significant problem of the Vee-Balloon concept is withstanding environmental conditions. In the temperature range of -65° to +160° F, considerable problems could arise. One inch of surface ice on the balloon could cause it to come down, at least until the lift and weight balance is achieved. The wind conditions specified would present additional severe problems. Lighting the balloon according to FAA specifications is another area of difficulty due to the fact that the balloon concept presents a definite aviation hazard. Also tactical vulnerability is a problem to be considered.

Logistic supply must be considered in terms of providing gas for the balloon. Helium, which would be required in large quantities, must be transported in pressure vessels which are heavy. Another gas supply could come from a hydrogen generator, but the hazards to personnel are considerable.

For this application, this concept is not considered the optimum, particularly in terms of down-time, system reliability, and logistical supply.

b. ANALYSIS AND RECOMMENDATIONS

The inflatable types of support structure, the Snap-Out scaffold type, and the collapsable tilt-up type all are capable, to varying degrees, of satisfying system requirements. As a basis for comparison, all are compared with a 300-foot umbrella antenna requirement.

On the basis of stage of development and availability, the structures are rated in order as follows:

(1) Snap-Out towers are in production stage.

(2) Collapsable tilt-up design is in production in smaller configuration, but not in production in size required here.

(3) Goodyear inflatable towers have been built in relatively small configuration, not developed yet for 300-foot size.

(4) Birdair inflatable towers are not yet designed or developed.

Considerable design effort, with corresponding stress analysis, has yet to be accomplished for inflatable types. Many design and production problems remain to be solved in regards to materials and methods.

In order of estimated initial cost, the support structures considered are as follows, least cost structures first:

(1) Snap-Out scaffold tower (approximately $30,000 per system)

(2) Collapsable tilt-up tower (comparable to above configuration, but more guys and accessory equipment should require higher initial cost).

(3) Birdair inflatable (budgetary estimate of $110,000 quoted per system).

(4) Goodyear inflatable (cost not known, but should be comparable to above).

The cost of maintaining the equipment during operation should also cause the structures above to be rated in the same order, assuming the higher initial cost reflects more sophisticated and complex equipment.

The specified environmental conditions of one inch of ice on the tower and one-half inch on the guys are particularly severe in the case of inflatable structure. For example, a 300-foot cylinder of five foot diameter, a surface area of 4700 ft^2 is involved. The weight of ice to be supported would be as follows:

$$(4700)\left(\frac{1}{12}\right)(56\ \text{lbs/ft}^3) = 22,000\ \text{lbs}$$

In addition, if more guys are required to provide column stiffness and to prevent buckling, additional ice loading will result. The wind loading is also much higher due to the large diameters involved for an inflatable structure.

An additional consideration is suitability to tactical environment. It is obvious that any 300-foot structure will not be difficult to be seen, but the much larger sillouette of the inflatable structure makes it more vulnerable to small arms fire. A continuous pressurization system could overcome the effects of a certain amount of leakage, but it would not withstand any significant amount of gunfire. The triangular aluminum tower would be less vulnerable to such conditions.

In terms of weight and volume, all systems considered would require two packages instad of the single specified package, thereby, doubling the weight and volume requirements. However, all packages would be capable of being transported in standard military vehicles. Each package would also be adapted to attachment to a standard 463L "rail" system pallet.

In general, the more rugged and simple design of the aluminum towers would require less training of personnel and better reliability and maintainability performance over the design lifetime of two years. Rough handling and abuse encountered in tactical situations is unavoidable, and a system which has the most rugged and simple design will have the least amount of down time. If a portion or section of an aluminum type tower is damaged in the field, the system may be still erected at a slightly lower height. However, an equivalent amount of damage to an inflatable tower would put the entire system out of operation.

In view of the aluminum construction towers having superior performance in terms of availability, reliability, maintainability, compliance to environmental condition specifications, and tactical capabilities, the inflatable concepts could not

be recommended as being the optimum support structure for this requirement. Of the two types of aluminum towers, the Snap-Out scaffold-type tower system would be considered more desirable for this application than the collapsible tilt-up tower because of the additional weight and volume required for the erection equipment, additional guys required (4-way guying instead of 3-way guying), and slightly higher weight of the tower (10 lbs/ft vs. 13.3 lbs/ft estimated). The results of computer run no. 17 show the safety of the tower when a man is on the tower. With proper safety precautions and training, the requirement for climbing the Snap-Out scaffold-type tower during erection is not considered objectionable to the extent that this concept should not be recommended.

It should be pointed out, however, if the high man concept is considered objectionable, the Snap-Out as well as the collapsible-type aluminum tower concepts are both suited to erection by the tilt-up procedure.

A comparison of weight differential of the "high-man" and the tilt-up techniques for the "snap-out" tower is as follows:

	high-man wt. pounds	tilt-up wt. pounds
guys	255	345
anchors	1500	1800
A-frame	----	400
misc. hdw.	----	150
	1755	2695

differential------------------+ 940 lbs

5. RADIATING CONDUCTORS

Three materials were considered for use as radiators for the antenna umbrella: Alumoweld, phosphor bronze, and jacketed Glastran. A diameter of 3/16 inch was used as a standard of comparison due to the results of electrical considerations. The following chart compares the properties of the above materials.

MATERIAL	WT/FT lbs	CORROSION RESISTANCE	HANDLING EASE	E psi
Alumoweld (3# 12)	.044	Excellent	Fair	23.5×10^6
Phosphor Bronze	.070	Excellent	Excellent	10.5×10^6
Jacketed Glastran	.034	Excellent	Good	6.0×10^6

Alumoweld is a common material in use as antenna radiator material. It consists of a steel core covered with an aluminum jacket, combining strength with good conductivity. Alumoweld has the property of "self-healing". When the aluminum is nicked through to the steel core, the galvanic actions resulting from the exposure "heals" the damaged surface as opposed to copperweld wire, which has

the opposite reaction resulting in the sacrificing of the steel core. Alumoweld, however, is stiff and would be relatively difficult to handle during erection or striking of the antenna. In addition, the high modulus of elasticity (E) would tend to restrict the displacement of the top of the tower during loading, thereby creating excessive bending in the tower structure.

Phosphor bronze is widely used for antenna radiators where resistance to salt water and atmospheric corrosion is prevalent. It is very flexible and easy to handle during erection or stricking of the antenna. Phosphor bronze is the heaviest material considered, weighing twice as much as the jacketed Glastran. In total weight for a 300-foot tower with 9 radiators, 250 pounds of phosphor bronze would be required. Phosphor bronze, like Alumoweld, has a relatively high modulus of elasticity, resulting in limitation of tower deflection under load, causing excessive bending stresses in the tower structure.

Jacketed Glastran radiators consist of a conventional Glastran rope with a harded jacket of aluminum, in turn jacketed with 20 mil polyurethane to prevent handling damage and sunlight resistance. The jacketed Glastran has the lowest weight of the materials considered (125 pounds total), and the lowest modulus of elasticity. By using the smaller diameter Glastran radiators as compared to the Glastran guys at the other support levels of the tower, the tower deflects linearly with height, resulting in the minimum of stress in the tower structure. An added feature of the jacketed Glastran conductor is that the non-radiating portion of the umbrella (lower end which connects to ground anchors) is a continuance of the radiator with the aluminum braid eliminated. This results in elimination of special hardware for terminating the radiator, with the exception of corona rings.

Although some care in handling must be exercised to prevent sharp bends or kinks in the jacketed Glastran, it is considered to be the most suited for this application.

6. GROUND SCREEN

a. MATERIALS CONSIDERED

It has been determined that a no. 12 conductor of 30 percent conductivity provides an adequate ground screen when arrayed in the form of 40 radials, each 300 feet in length. The following materials have equal or better conductivity, and were considered on the basis of mechanical properties.

Wire Material	ohms/1000 Ft.	wt./1000 Ft., lbs.
#10 Copperweld	3.39	28.81
#13 Aluminum	3.29	4.76
#15 Copper	3.18	9.86
#8 Alumoweld	3.09	37.03

b. ANALYSIS

Copper materials have an advantage over aluminum when used in contact with the soil in that aluminum tends to corrode in contact with soil at a rate depending on the type of soil involved. In the case of this application, the aluminum wire, if

used, lays on top of the ground rather than buried, which would limit the corrosion process to a degree.

The total quantity of wire required for the ground screen is 12,000 feet. As shown in the above table, no. 13 aluminum wire is the lightest, resulting in a total system weight of wire of 57 pounds, as compared to 376 pounds of copper wire.

The aluminum wire would offer additional advantages of less cost, ease of handling, and a minimum of storage volume.

In view of the above considerations, it is felt that no. 13 aluminum wire would be most desirable for this application, although after an extended period of time it might have to be replaced due to corrosion.

In place of conventional copperweld ground rods used to periodically connect to the ground radials, it would prove beneficial in terms of weight to use a 2-inch arrowhead anchor together with a length of phosphor bronze cable to be used to connect to the ground wire, and to retrieve the small anchor. A bimetallic connector would be required for each grounding anchor. The per unit weight is approximately 0.3 pounds for the grounding anchor vs. 0.85 pounds for the ground rod.

7. GUYS

a. GENERAL

Materials considered applicable for comparison included "Nolaro" Dacron, Dacron, Mylar, Polypropylene, Nylon, and Glastran ropes. Table XIV represents a comparison of physical properties, table XV a cost comparison, and figure 68 shows comparative strengths of various guy materials. An evaluation of guy materials follows.

b. MATERIALS CONSIDERED

(1) Guy ropes of Dacron polyester fibers have been in use for several years. Dacron has a high strength to weight ratio, has good abrasion resistance, is very easy to handle, and has good weathering characteristics.

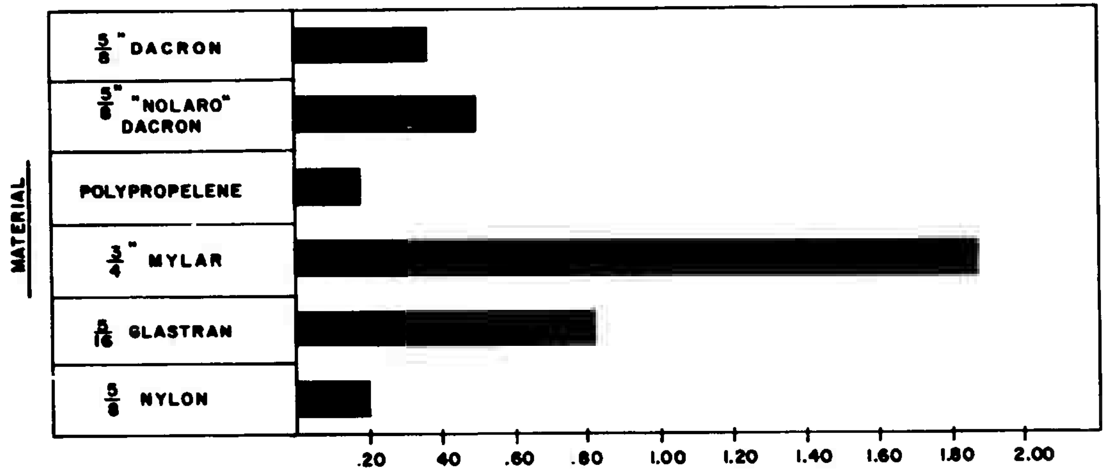
End fittings found suitable for Dacron ropes are compression sleeves such as made by National Telephone Supply Co., and conventional eyesplicing, which allow loads of 80 percent or greater of the breaking strength of the rope.

The elongation of a "broken in" Dacron rope (one preloaded to "set" fibers which removes un-recoverable elongation) is approximately 5 percent at a 20 percent breaking strength loading. This is at an acceptable level for structure of moderate height and environmental loading, but, at a height of 300 feet, excessive deflection would result in the tower structure.

(2) Nolaro Dacron

The Nolaro term results from the construction of the rope which has no "lay" of the individual fibers. Any type of fiber may be used in a Nolaro construction, which consists of paralleled fibers thrown into a slack twisted yarn, after which a suitable number of yarns are paralleled under equal tension and held together in a bundle protected by an extruded plastic jacket. This type of construction reduces

TABLE XV. COST/FT. EQUIVALENT ROPE DIA.



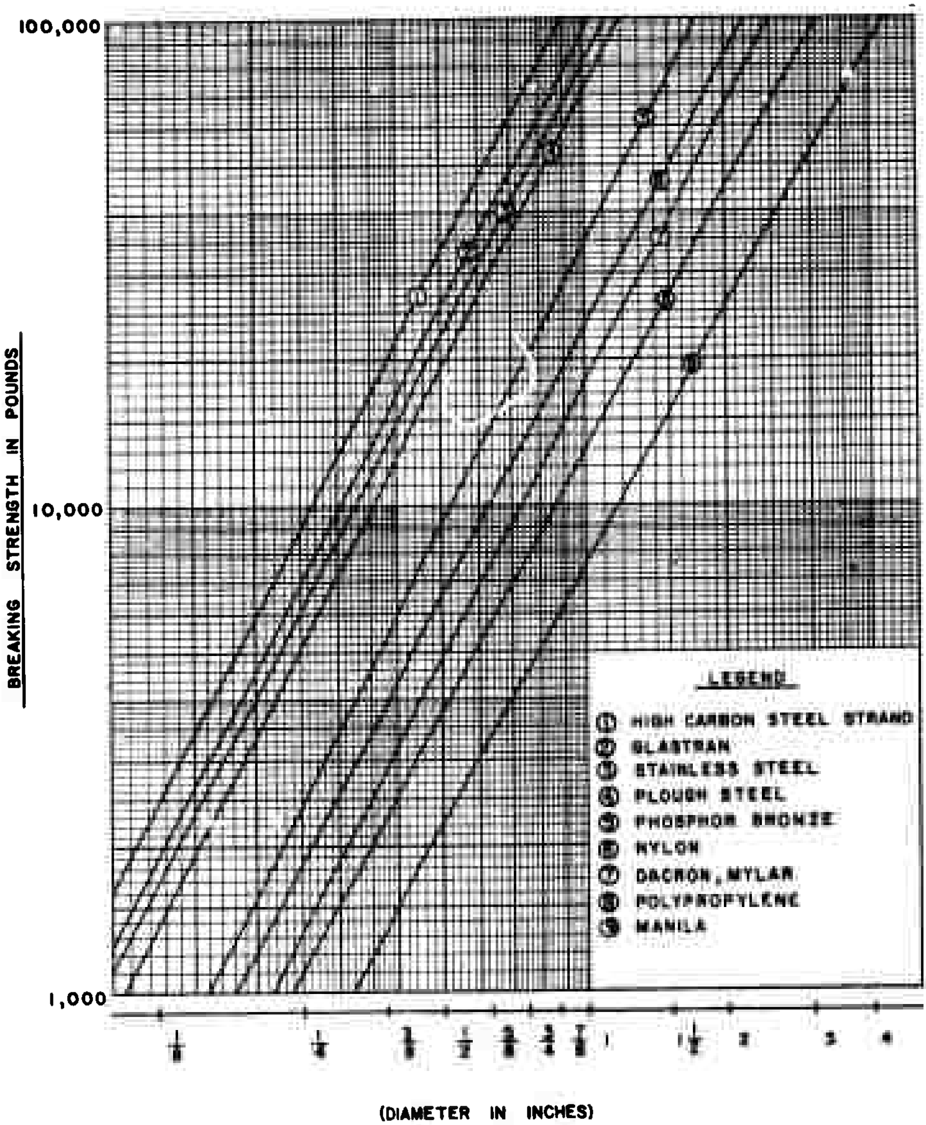


Figure 68. Comparative Strengths of Ropes and Wires

abrasion between individual fibers and does not introduce elongation due to the lay of conventional rope. The breaking strength of the Nolaro Dacron rope is higher than the conventional Dacron rope due to the elimination of internal abrasion of fibers during loading.

Eyesplicing, while more difficult than with conventional lay ropes, can be accomplished on Nolaro Dacron rope. An alternate method which produces load capacities of 80 percent of the breaking strength is to remove a portion of the jacket, and socket the rope in a tapered end fitting with epoxy resin (small dia = rope dia + .010, and large dia = 1.5 to 2.5 rope dia, and length of cavity 2-5 times rope dia.)

The elongation of Nolaro Dacron rope is approximately 1.8 percent at 20 percent of the rope breaking strength. This is a considerable improvement over conventional lay Dacron rope, but is still approximately four times the spring rate of a steel guy cable. Through careful analysis a 300-foot tower could be guyed successfully with Nolaro Dacron.

(3) Nylon

Nylon is the strongest of the conventional synthetic ropes. However, due to its excessive elongation (22 percent at 20 percent of breaking strength) it would be unsuitable for this application.

(4) Mylar

Mylar is unique in construction, being made from 3/4-inch wide by 1/1000-inch thick Mylar film, which has been heated and stretched into a fine thread to remove all but about 5 percent of its elongation. These threads are then woven into a low twist lay rope to minimize load elongation. Mylar possesses all the attributes of Dacron rope, with a slightly lower breaking strength. However, it has an elongation of only 2 percent at 20 percent of breaking strength, which makes it suitable for guying a 300-foot tower.

(5) Polypropylene

Polypropylene like Nylon, has excessive elongation under load for a 300-foot tower application, approximately 16 percent at 20 percent rope breaking strength loading.

(6) Glastran

Glastran is a glass fiber rope, constructed of continuous filaments of high strength glass impregnated with epoxy resin. Filaments are stranded together, and the strands woven into a conventional rope lay.

To protect the rope from u-v radiation, and to provide abrasion protection, the rope is jacketed in extruded plastic, usually polyurethane.

The elongation of Glastran is very low, .67 percent at 20 percent breaking strength loading. As shown in table XIV, Glastran has nearly the same properties as stainless steel aircraft cable of the same diameter, with the exception that Glastran weighs 1/4th as much as the stainless steel cable.

Glastran may be terminated by means of a preformed dead end, such as supplied by Preformed Line Products Co. These have been tested to 100 percent of the breaking strength of the rope. To install a preformed dead end, the plastic jacketing of the Glastran must be removed under the area of contact with the dead-end. Tests were run using the preformed dead end directly over the jacketed Glastran, and failure occurred at approximately 80 percent of the rope breaking strength. The rope may also be terminated with epoxy resin in a socket-type end-fitting, with approximately 20 percent loss in load rating.

A problem exists with Glastran guying in that the rope strands may be broken under severe bending, such as being driven over by a vehicle. This, a partial break of the rope would not be readily visible due to the opaque black plastic jacketing. Care in handling of Glastran guys would be mandatory. Field repairs of Glastran can be made easily and quickly by cutting out the damaged section, removing necessary jacketing, and installing a preformed splicing sleeve, resulting in a joint that equals the rope breaking strength.

c. ANALYSIS

Of the materials considered for guying Mylar, Nolaro Dacron, and Glastran are capable, to varying degrees, of meeting desired requirements. As a basis for comparison, a 300-foot guyed tower will be used, requiring approximately 4500 feet of guy rope. The system guy weight requirements are as follows:

Nolaro Dacron	615 pounds
Mylar	750 pounds
Glastran	255 pounds

Glastran offers a weight savings of 360 to 495 pounds over Nolaro Dacron and Mylar, which is a significant amount.

In terms of strength and elongation, Glastran has a significant advantage in that its elongation at 20 percent rope breaking strength is .67 percent, or 2.5 to 3 times less than Nolaro Dacron or Mylar. This is an extremely important property, in that the tower structure is subjected to a much less severe loading caused by deflection of guy supports. This deflection results in additional bending movements in the tower structure, necessitating a stronger tower. In addition, the tower is subjected to a lesser degree of fatigue loading.

An additional consideration in regards to tower loading effects caused by the guys is the diameter of the guy rope. A 5/16-inch diameter Glastran rope possesses strength equal to a 3/4-inch diameter Mylar rope and a 5/8-inch diameter Nolaro Dacron rope. The weight of accumulated ice increases with the square of the diameter, and the wind loading is directly proportional to the diameter. The advantage of Glastran is obvious in this case.

As shown in table XV, Glastran is approximately 1/2 as expensive as Mylar, and 34 cents per foot more than Nolaro Dacron. From a system cost basis, Glastran would cost approximately $3,700 per system, while Nolaro Dacron guys would cost approximately $2,150 per system.

In the event field damage occurs Nolaro Dacron and Mylar could be repaired by splicing. This necessitates that a crew member present be familiar with this process. Glastran is field repairable by application of a preformed splice joint, which must be supplied with the system. No particular skill is required for its application. Barring any unusual physical damage, any of the materials considered has a life expectancy far in excess of the specified two years.

The comparative analysis of guy rope materials above leads to the conclusion that Glastran guy rope is recommended for this application.

d. ASSOCIATED EQUIPMENT

The device shown in figure 69 is a combined guy tensions and tensiometer produced by Up-Right Tower Company. A calibrated spring mechanism reads out guy tension at all times. A removable handle eliminates considerable weight, by being moved to each anchor during adjustment. This unit is ideally suited to this application.

8. ANCHORS

a. GENERAL

Anchors considered for comparative analysis include expansion anchors, screw-in type anchors, dead man type anchors, arrowhead anchors, and explosive installed anchors. Equipment and accessories used in installation of the various types of anchors are also considered. As an aid in determining the type and size of anchor best suited or a specific job, classification has been made of anchor holding strengths in different types of soil and under different moisture conditions (see figures 70 and 71). Classification of holding power on the basis of soil type alone has been found to be insufficient, not only from the standpoint of soil identification, but also because of variations experienced in the holding power values.

Numerous tests under different moisture conditions and in all types of soil have proven moisture content to be a greater factor than soil composition in determining soil-anchor holding power. The following soil classifications as developed by A. B. Chance Co., Centrailia, Mo., give consideration to both the type of soil and the moisture content, providing a more accurate and easily-recognized means of soil identification.

Class 1. Hard rock (solid)

Class 2. Shale, sandstone (solid or in adjacent layers).

Class 3. Hard, dry (hardpan). Usually found under a Class 4 strata, resembling soft rock.

Class 4. Crumbly, damp, (usually clay predominates. Insufficiently moist to pack into a ball when squeezing by hand. Particles crumble off).

Class 5. Firm, moist (usually clay predominates. Other soils commonly present. When squeezed by hand will form into a firm ball. Most solids in well drained areas will fall into this classification).

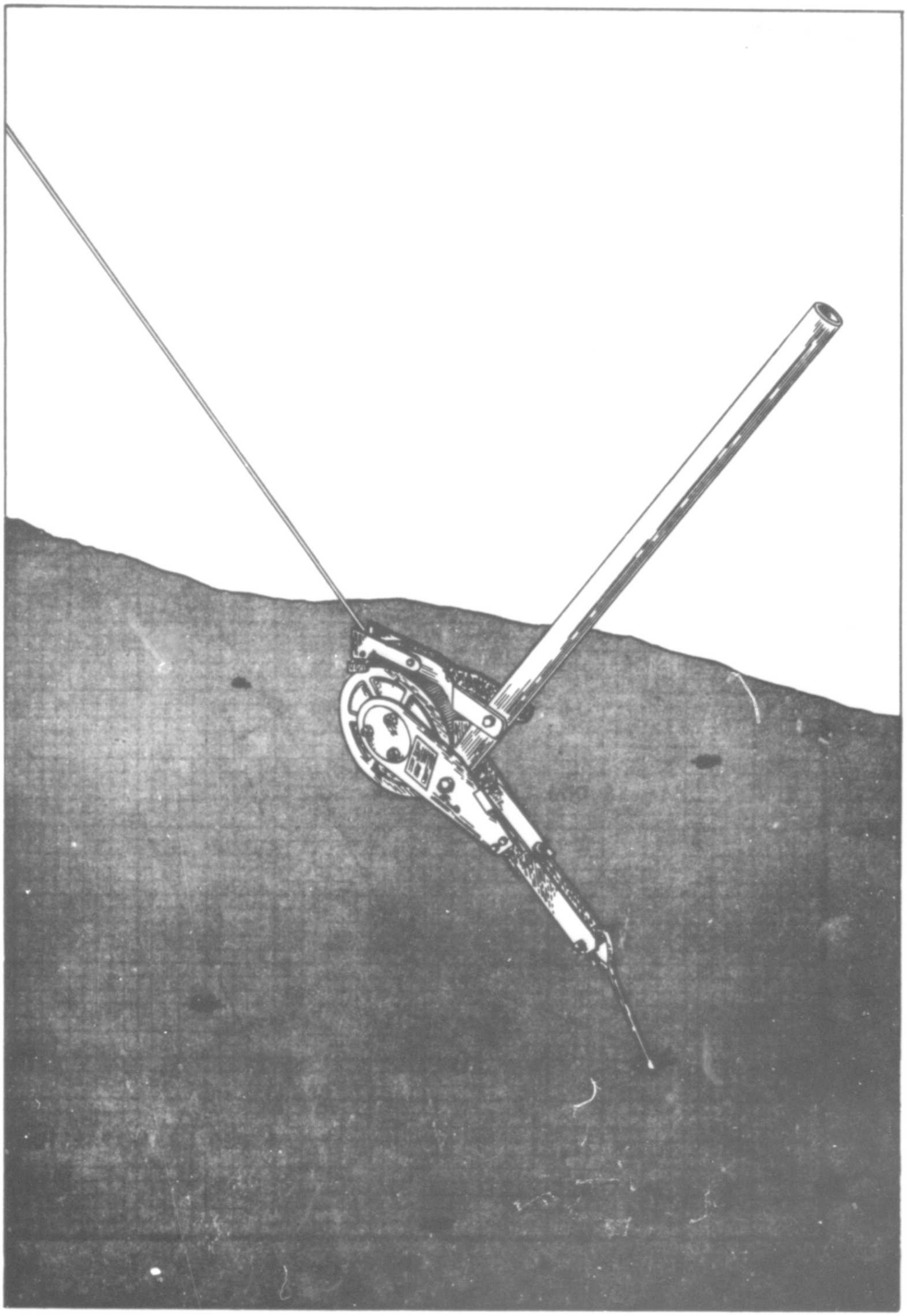


Figure 69. Guy Adjuster and Tensiometer

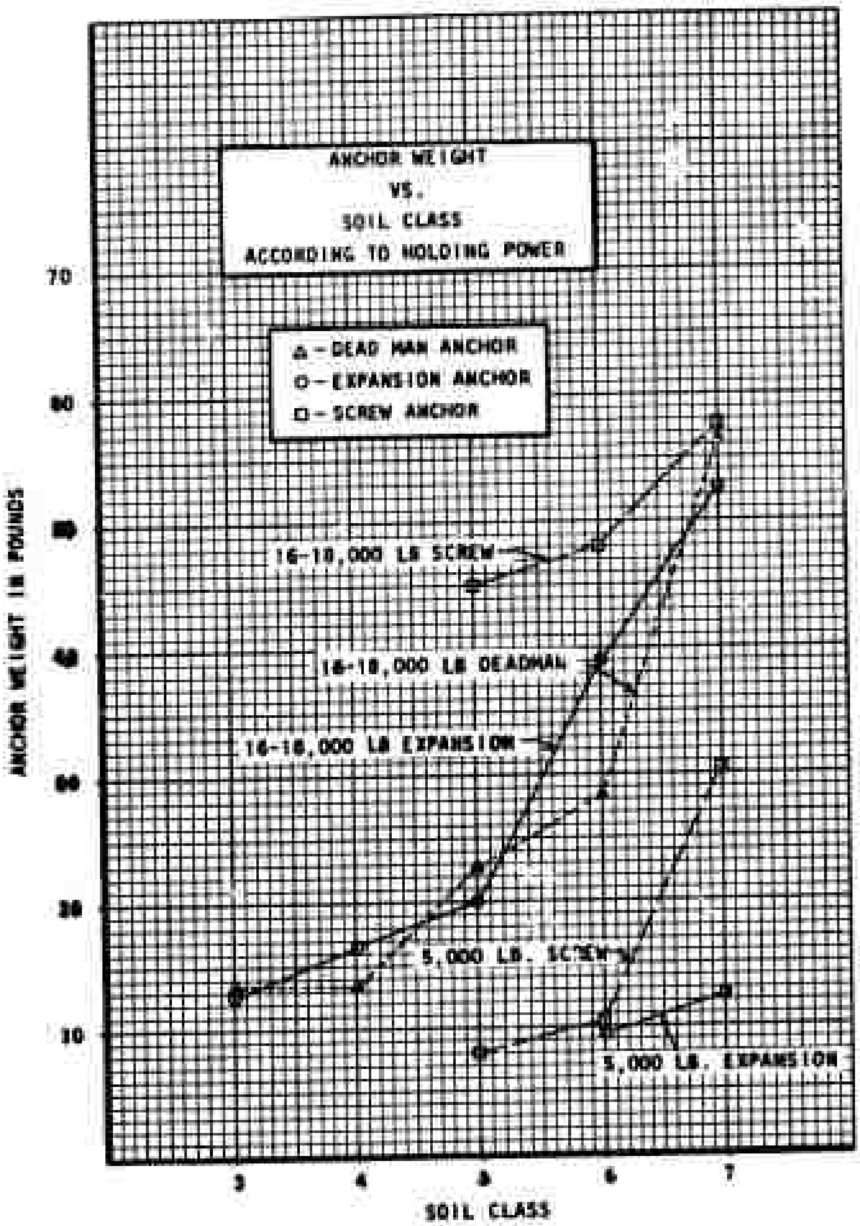


Figure 70. Soil Class

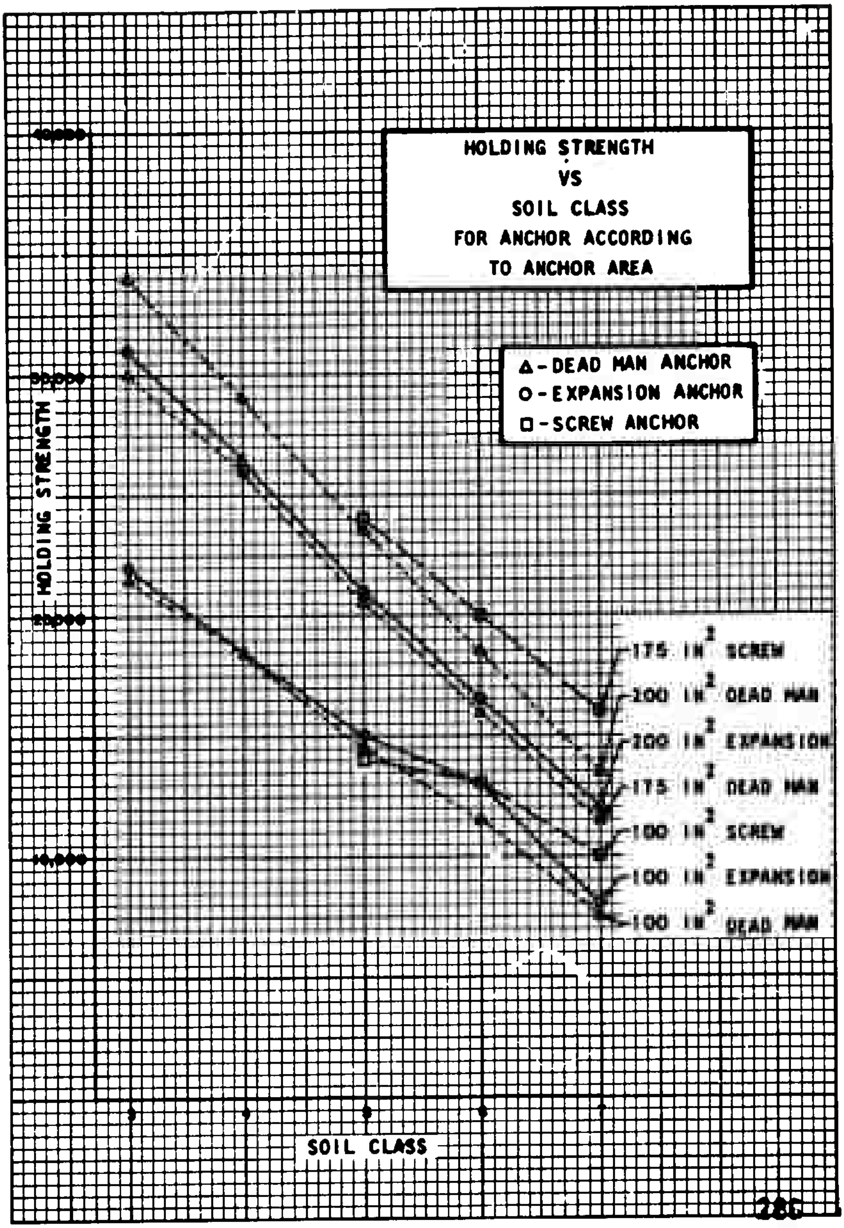


Figure 71. Soil Class

Class 6. Plastic Wet, (usually clay predominates as in Class 5. Due to unfavorable moisture conditions such as areas subjected seasonally to heavy rainfall, sufficient water is present to penetrate the soil to appreciable depth and though the area is fairly well drained, the soil during such seasons becomes plastic and when squeezed will readily assume any shape. The soil is not uncommon in fairly flat terrain).

Class 7. Loose, Dry (found in arid regions; usually sand and gravel predominates. Filled in or built up areas in dry regions fall into this class. As the term implies, there is very little bond to hold the particles together).

Loose, Wet (same as Loose, Dry, for holding power. High in sand, gravel, or loam content. Holding power at some seasons good, but during rainy seasons absorbs excessive moisture readily with resultant loss of holding power. Predominant in poorly drained areas. This Class also includes very soft wet clay).

Class 8. Swamps and Marshes (including areas that are marshes only seasonally).

b. ANCHORS CONSIDERED

(1) Expansion Anchors

A typical expansion anchor is shown in figure 72. These anchors are rugged, simple, and can be installed with a reasonable amount of effort provided hole boring equipment is available. The principle of operation of the expansion anchor involves insertion of the anchor and rod into a bored hole, filling and tamping the hole, and setting or expanding the anchor by exerting a force on the anchor rod. After expansion, the anchor exerts force into undisturbed earth, providing good holding power after installation.

As shown in Table XVI, the expansion anchor may be used in most soil types. Important in the holding power of this anchor is the hole size and backfill practices. This anchor in type 6 and 7 soils would exhibit relatively greater creep if difficulty is encountered in back tamping soft or sticky soils. The anchor cannot be recovered after use. However, the rod may be removed for use at another site. As shown in Table XVII, the rod weight represents approximately 50 percent of each rod-anchor combination weight.

The hole required for installation may be made by a power driven auger, either electric, as shown in figure 76 or a conventional gasoline powered unit.

(2) Screw Anchors

Perhaps the most commonly used anchor for medium load requirements is the screw anchor. The type considered here is of all welded construction, rather than the type with threaded rod and head, due to the capability of the former to be retracted by turning in the opposite direction. The screw anchor may be installed by hand or machine. Figure 73 shows a screw anchor being driven by an electric

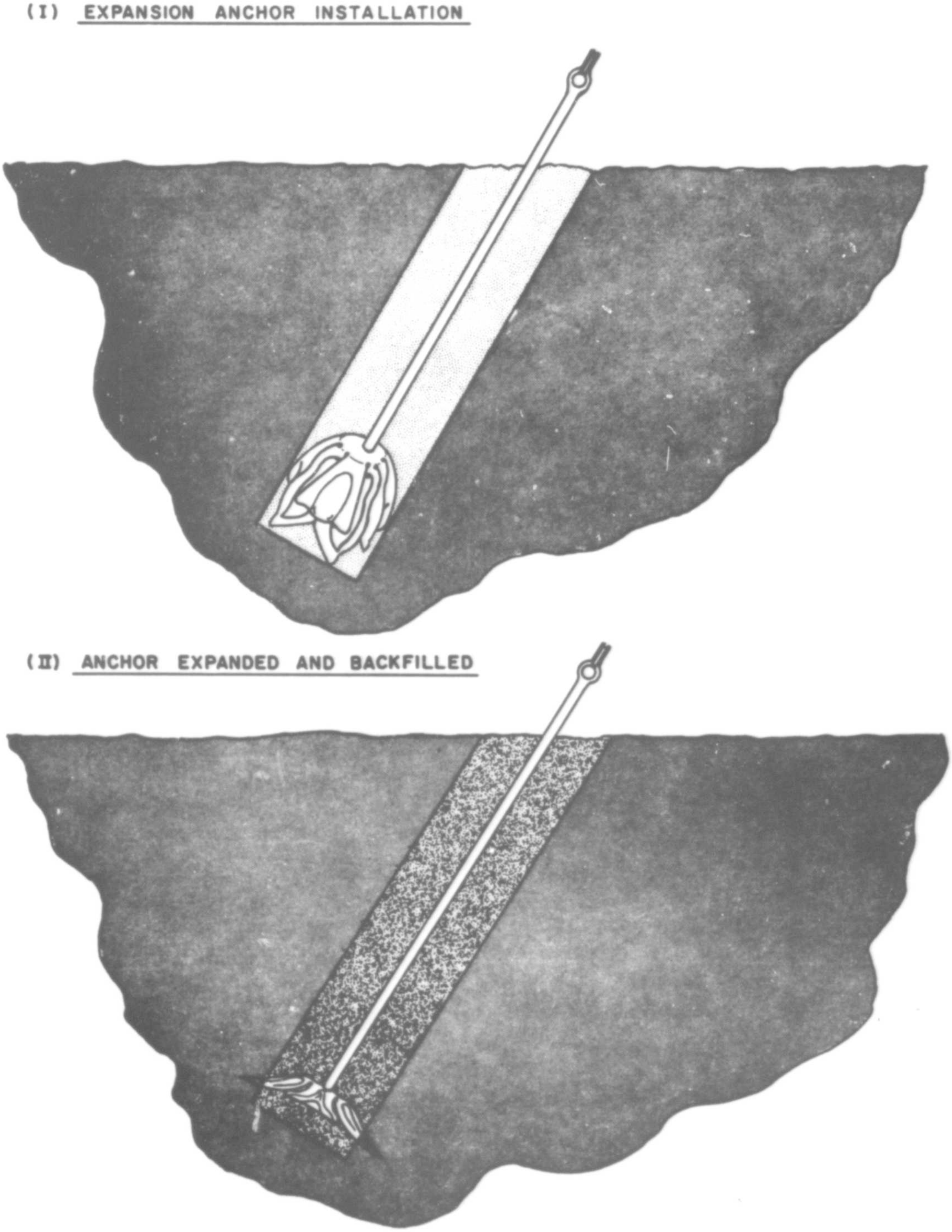


Figure 72. Expansion Anchor

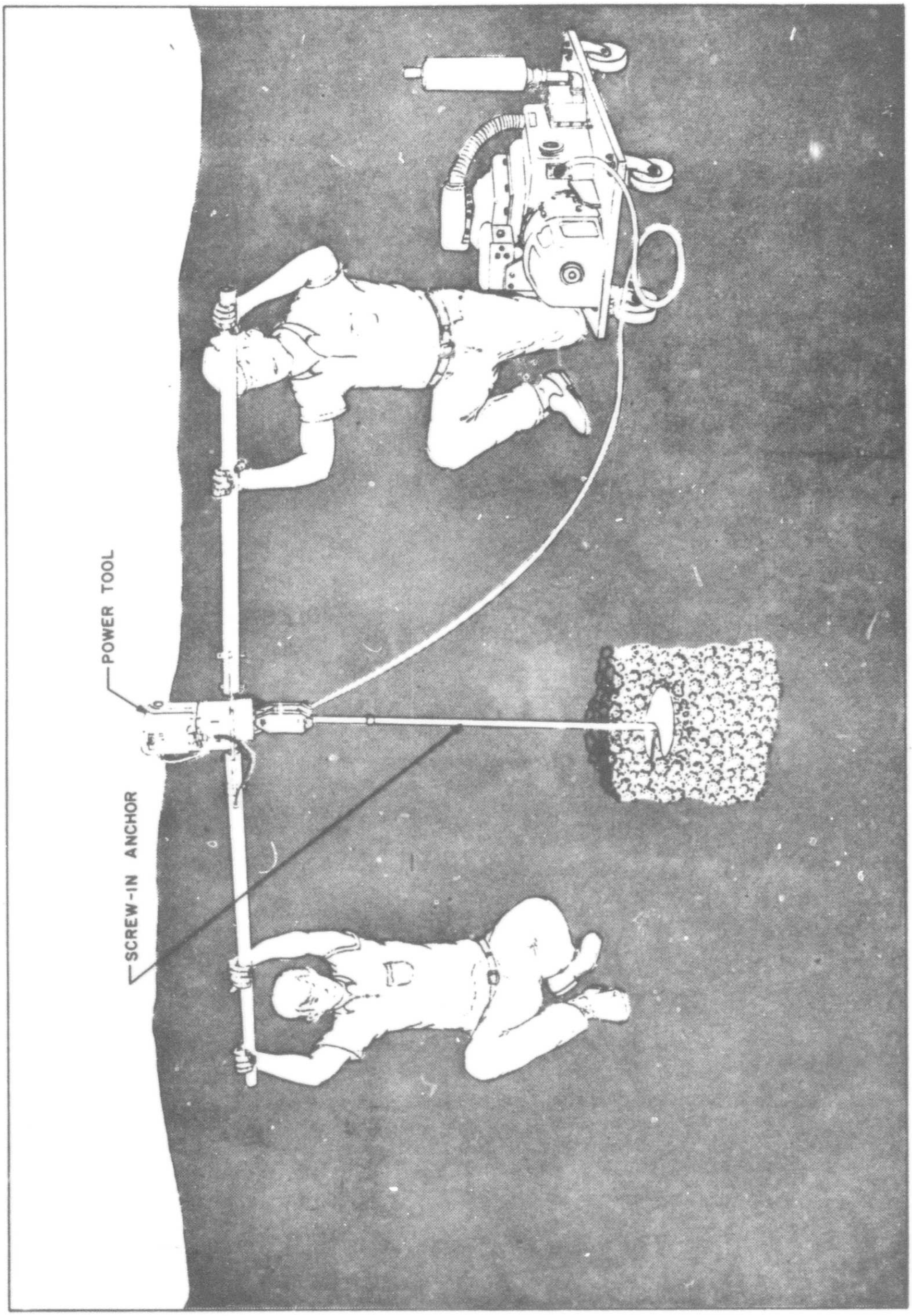


Figure 73. Anchor Installation - Power Tool

TABLE XVI. COMPARISON OF 16-18000 LB ANCHORS FOR CLASS 7 SOILS

ANCHOR TYPE	COMPARABLE INSTALLATION TIME (EST)	WT. LBS.	REUSABLE	SOIL CLASS USAGE	ACCESSORY EQUIPMENT REQUIRED
SCREW	2 MEN - 5 MIN.	58	YES	6-7	POWER TOOL
EXPANSION	2 MEN - 25 MIN.	53	ROD ONLY	ALL	POWER TOOL AUGER TAMPING TOOL
DEADMAN	2 MEN - 30 MIN.	57	YES	ALL	POWER TOOL AUGERS WINCH FOR RECOVERY TAMPING TOOL

TABLE XVII. ANCHOR WEIGHT COMPARISON 16-18,000 LBS. CAPACITY

ANCHOR TYPE		SOIL CLASS				
		3	4	5	6	7
EXPANSION	ANCHOR WT.	5.2	9	9	19	33
	ROD WT.	7.4	7.4	10.8	20	19.7
	HOLE SIZE, IN	8	8	8	10	12
DEAD-MAN	ANCHOR WT.	5.5	5.5	10.6	16	34
	ROD WT.	7.4	7.4	12.2	12.2	22.5
	HOLE SIZE, IN	6	6	6	8	8
SCREW	ANCHOR WT.			44.9	48	57.8

power tool developed by Collins Radio Company. An 8-inch diameter screw anchor may be driven in 2 to 4 minutes by two men in average soil.

Due to a minimum of soil disturbance, screw anchors perform well in most soil classes. As the soil becomes harder, the maximum loads carried by dead man and expanding anchors exceed that of screw anchors. Also, installation of screw anchors in harder soil becomes more difficult, as evidenced in an evaluation at Fort Huachuca,[23] Arizona, in which screw anchors could not be driven successfully, and holes had to be dug with power tools and explosives in the hard, rocky soil at the site.

(3) Dead-Man Anchors

The dead-man plate type anchors, illustrated in figure 74, are particularly suited for heavy guy loads. These anchors pull against solid, undisturbed earth, and are not dependent on the quality of a tamped backfill for holding power.

Installation of the dead-man anchors are illustrated in figure 74. A machine bored hole is required for installation of the anchor. Dependent on soil conditions, the rod may be either driven or inserted in a small diameter machine bored hole. After the rod is secured to the anchor and the anchor pulled against the undisturbed earth, the hole is filled, tamping not required or desirable.

To retrieve the anchor, the rod is detached and pulled out. Then by use of a winch, the plate anchor may be retrieved by pulling on the retrieving cable. This retrieval method is not used commercially, due to the fact that these anchors are not required to be removed in general use. Retrieving of the plate anchor will require a pull force depending on soil conditions and length of time since installation. Since tamping of the soil filling the anchor holes does not add to the pulling power of the anchor, it is desirable to leave this back fill loose to facilitate removal of the anchor.

As shown in Table XVII, the dead-man and the expansion anchor weigh approximately the same, but a smaller hole size is required for installation of the dead-man anchor.

(4) Arrowhead Anchors

The arrowhead anchor, as produced by Laconia Mallable Iron Company, is Military approved and covered in 4-, 6-, and 8-inch sizes by MIL-A-3962A. These sizes are not of sufficient holding strength for this application, but a 16-inch version of the same anchor is rated as follows:

Anchor Size	Area	Guy Line Length	Weight	Holding Strength, lbs		
				Sand	Clay	Hardpan
16"	128 in^2	optional	20 lbs	11,500	21,000	27,500

The weight above does not include the guy line and hardware, which would weigh approximately 5 pounds.

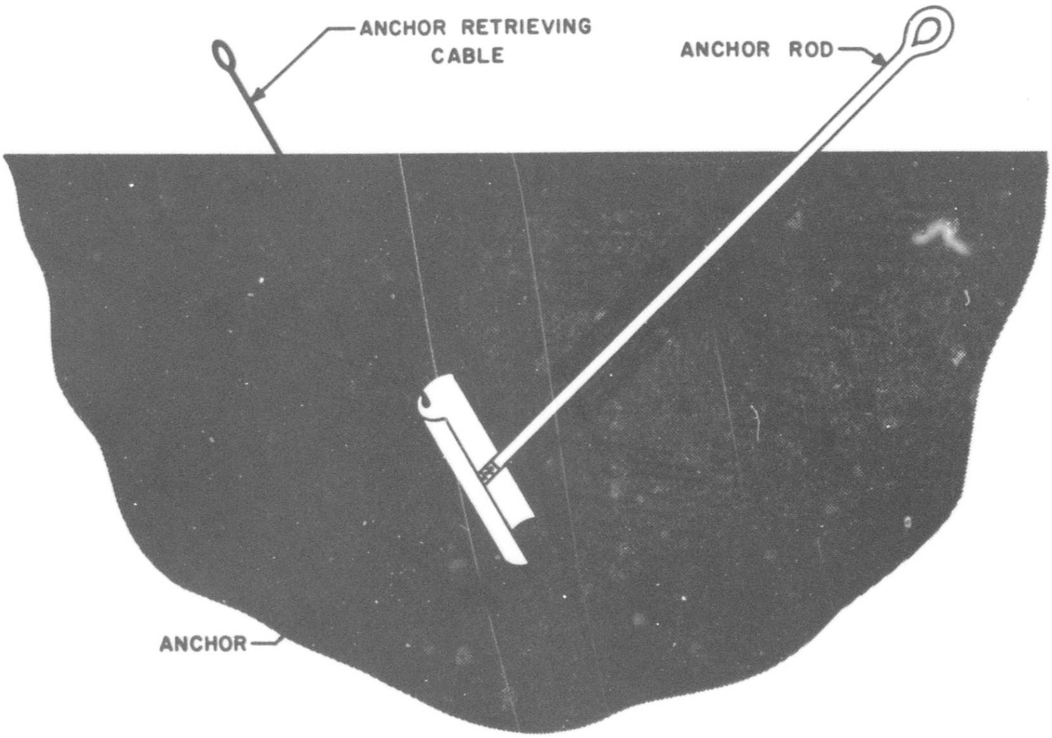


Figure 74. Dead Man Anchor

The operation of the arrowhead anchor is shown in figure 75. The anchor has a steel pin over which a driving rod is positioned. The anchor may be driven by sledge hammer, impact tool or by air or electric hammers, if available. For tactical application, the sledge is assumed to be used. When the anchor is driven to the length of the cable, the driving rod is removed. At this time, a preload must be applied to the anchor, which turns the anchor at right angles to the guy cable. During this operation, the anchor will rise 2 to 6 inches.

An example of the application of this anchor is the AN/TSA-17antenna group,[22] a lightweight tactical hf antenna. During development of this antenna, 4- and 6-inch arrowhead anchors were evaluated by Collins Radio Company, in soil which would fall into class 5. It was found that the 4-inch anchor and 6-inch anchor developed approximately equal holding strength of about 2500 pounds immediately after being driven. Since a load requirement higher than 2500 pounds existed, two 4-inch anchors were bridled together to provide the desired holding strength. These anchors are equipped with a retrieving cable, attached to one corner of the anchor. To retrieve the anchor, a winch is attached to the retrieving cable, and tension on the corner of the anchor turns the anchor edgewise, and the anchor is pulled from the ground.

Field reports on the AN/TSA-17 have indicated that the 4-inch arrowhead anchors hold very well in average soil. The retrieving process is not 100 percent effective, in that considerable tension is required on occasion to pull out the anchor, occasionally breaking retrieving cables.

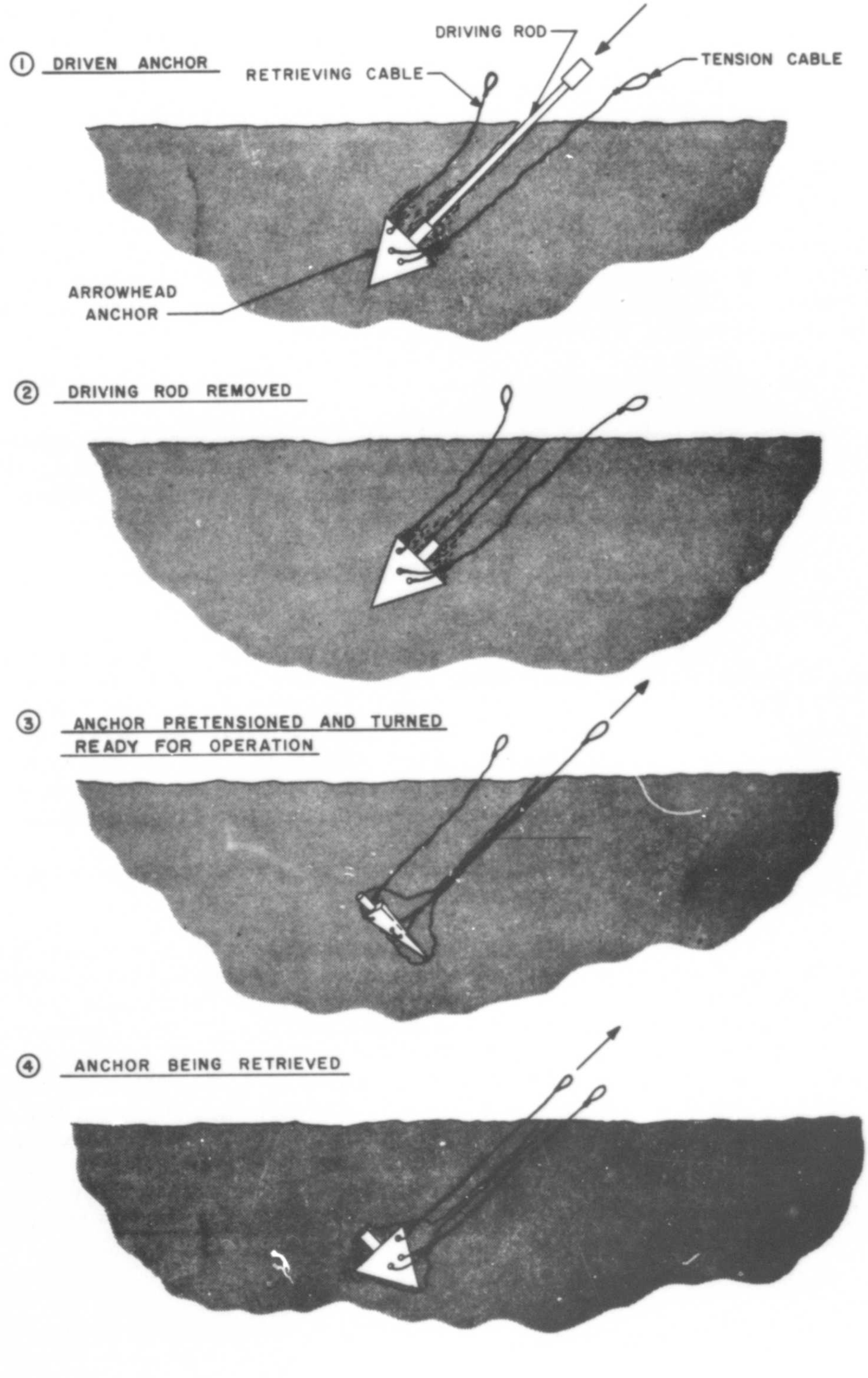


Figure 75. Arrowhead Anchor

An investigation conducted by Haley and Aldrich[24] reports on tests of holding power of arrowhead anchors. However, the tests conducted where in sand only, and results for the 16-inch anchor were not satisfactory. All other holding strengths used for the arrowhead anchors are based on theory. Interesting to note is the fact that their tests on 4 and 6 inch anchors substantiated Collins Radio Company's tests in that no increase in holding power was noted, in fact the 6-inch at 735 pounds did not equal the 800 pound pullout force of the 4-inch anchors.

On the basis of experience, field reports, and what test results are available at this time, arrowheads would be considered applicable to light, transportable structures. However, on large structures such as the subject of this study, it is recommended that these anchors not be used until the theoretical operation of the larger 16-inch arrowhead is proven by extensive testing.

(5) Explosive Ground Anchors

Two manufacturers of explosive anchors provided two distinct approaches to an anchor design utilizing an explosive to aid in its installation. The Seastaple produced by the National Water Lift Company, is a cartridge actuated device intended for use as a sea or mooring anchor.

Harvey Aluminum manufactures the Earth Rivet for use in general purpose anchoring requirements.

The Seastaple anchor is a forcibly embedded dead-man type anchor ideally suited for precision or hard bottom mooring. An electrically fired cartridge in the body of the anchor supplies the force needed to drive the anchor. The inverted cone or bell at the top of the housing provides recoil absorption through the column of water (10 feet minimum) above the cone. The anchor head fired into the earth then functions similarly to the arrowhead anchor previously discussed. The gun or body of the anchor is to be returned to the factory for inspection after firing 10 times.

The National Water Lift Company has no existing design for a surface anchor, and no present plans for its development.

The Harvey Earth Anchor, shown in figure 76, is a surface anchor as opposed to the Seastaple, which functions under water. Figure 76 also illustrates the steps involved in installation of the Harvey Earth Anchor. A 2-inch diameter, high strength steel tube is driven into the ground or inserted into a 2-inch diameter drilled hole, depending on soil conditions. After the tube is in the ground, detonation of a small explosive charge, approximately 1/10 of a pound of RDX explosive, forms the lower end of the tube into umbrella-like "tines." The explosive charge, which is detonated electrically, also opens a highly compacted cavity (camoflet) underground which is filled through the tube with a quick-setting grout to form a large anchor head. Then a suitable termination fitting is attached to the tube for guy attachment. As little as 30 minutes is required for setting or curing of the grout, after which the anchor is ready for operation.

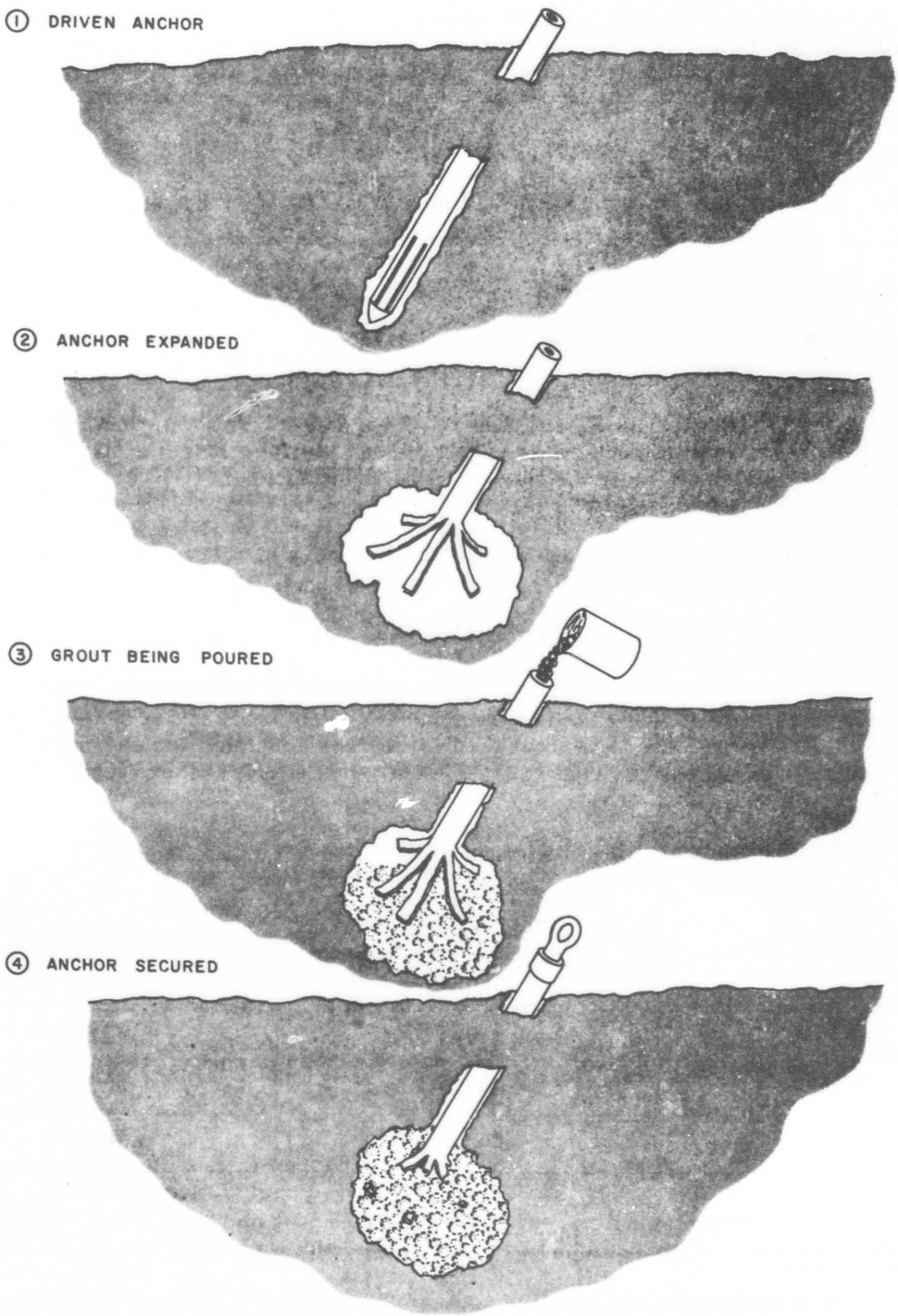


Figure 76. Explosive Anchor

Specifications of the Harvey Earth Anchor are as follows:

Anchor Size	Anchor Holding Strength, Lbs					
Dia for Emplacement	3	4	5	6	7	8
2"	40,000	40,000	38,000	30,000	20,000	20,000

Anchor weight: approx. 50 pounds

Grout wt/anchor: approx. 125 pounds (1 cu. ft.)

The Harvey Earth Anchor is in use by the U. S. Navy, and is used in the SATS program to secure the arresting gear mechanism which brings the aircraft to a stop similar to the technique used on aircraft carriers. The Harvey Earth Anchor is not re-usable, and a new set of anchors and grout is required for each erection. The logistic advantage of this anchor is that of a single type anchor is suitable for all applications. A source of water is required for mixing of the grout. In view of the system weight requirements, the Harvey Anchor would not be applicable.

c. ANCHOR INSTALLATION EQUIPMENT

Two types of anchor driving tools are available, conventional gasoline engine portable power units, made by various manufacturers, and the 280B-1 Anchor Driver, built by Collins Radio Company. Both types are adaptable for driving screw anchors, and boring holes in the earth to facilitate installation of other types of anchors.

A representative list of gasoline power units is as follows:

Auger Size Inches	Horsepower	Weight, Tool & Auger Pounds
2	3/4	16
8	2-3/4	45
12	4-3/4	82
16	6 to 9	90

These power tools are geared from 20:1 to 50:1 and have slip clutches to protect the operator and the equipment should an obstruction be hit.

An advantage of the gasoline powered unit is that it is free from the requirement of having a power cable required to reach all anchor points, in the case considered, 300 feet.

The 280B-1 anchor driver is an electrically powered, portable, hand-held unit designed for installing screw anchors. It can be adapted to drive a 5-ton winch, or can be adapted to drive an earth auger. It consists of a reversible, series-wound gearmotor, a baseplate, and two 4-foot handles. Specifications are as follows:

Direction of rotation:	reversible
Max output torque:	400 ft lb @ 40 rpm
Input power:	115 vac @ 25 to 60 cps
Current requirements:	5 amp - no load 16 amp - 120 ft-lb 35 amp - 400 ft-lb
Input connector:	Std 3 prong
Weight:	50 pounds
Stored dimensions:	20x18x51 inches

A rectifier must be used if 220-volt 400-cps power is to be used.

The adapter required for driving anchors may be removed to permit the power tool to adapt directly with a standard winch to be used in antenna erection, or to a standard earth auger for hole boring. The maximum hole in average soil that could be augered is 8 inches in diameter.

d. ANALYSIS

For a comparative analysis of anchors, a 300-foot tower guyed at 50-foot intervals is considered, with 9 radial wires at the top, for a total of 9 radial anchors, and 15 guy anchors. For a safety factor of 2, the guy anchors should have a holding power of 16 to 18,000 lb, and the radial anchors a holding power of approximately 5,000 pounds.

The screw, dead-man, and expansion anchors are capable in varying degrees of compliance with the requirements. In terms of re-usability, installation time and effort, and simplicity, the screw anchor is superior to the expansion and dead-man anchor, except in the harder classes of soil where the use of the screw anchor is not possible. Table XVI shows a comparison of the above anchors.

The total anchor weight using nine 5,000-pound screw anchors and fifteen 16-18,000-pound anchors would be approximately 1,140 pounds for class 7 soils. The weight of the expansion and dead-man anchors would be approximately the same for class 7 soils. However, for class 5 soils, the weight of dead-man or expansion anchors is less, 360 pounds opposed to 747 lbs.

In view of the considerable man-hour requirement advantage of the screw anchor (approximately 4 man-hours of actual direct installation time versus approximately 20 man-hours required for the dead-man or expansion anchor), it is recommended that the screw type anchor be supplied with the antenna system for use in class 6 and 7; also recommended to be included with the antenna system is a set of dead-man anchors suitable for soil classes 5 to 3, where the installation of screw

anchors becomes very difficult. The expansion anchor is not recommended for the reason that the anchor head is not recoverable.

As a final comment on anchors, it should be noted that the Harvey Anchor would be ideal for instances where a semi-permanent installation of the antenna system could be used, at which time the necessary anchors and grout could be shipped separately. A possible future development of the Harvey Anchor principle in which no grout would be required, and the anchor would expand itself similar to an expansion anchor, would possibly result in this anchor as the optimum for large transportable structures of this type.

The requirement for the power tool to drive the anchors and augers recommended exceed the present capability of the 280B-1 power tool, and a gasoline powered tool of at least 4-3/4 hp is recommended. Although the reliability and maintainability of the gasoline powered tool is not equal to the 280B-1, it is more than sufficiently capable of meeting the requirements of 15 to 20 erections of the antenna with a minimum of maintenance.

9. DATA PRESENTATION AND ANALYSIS OF LIGHTING SYSTEM

a. GENERAL

An antenna structure of the size and type discussed in this test is considered a hazard to air navigation and will normally require some type of obstruction lighting system. When considering the type of lighting to be used, the prime considerations must be the amount of light desired, the mode of operation (flashing or steady), and the specifications to be conformed to, if any.

b. SYSTEMS CONSIDERED

Three different light systems were considered and are presented herein:

(1) A system which complies in all respects to FAA - Specification A-2 for towers up to 300 feet in overall height.

(2) A system placing flashing lights at both top and midpoint of the tower.

(3) A system placing steady lights at both top and midpoint of the tower.

(a) FAA System

The first system shown in figure 77 consists of a 300-MM code beacon which mounts at the top of the tower, two single lamp obstruction light fixtures mounted at the midpoint of the tower, a flasher unit located near the base insulator, a photoelectric control cell located directly below the flasher and all interconnecting conduit junction boxes and cabling.

The 300-MM code beacon is a large unit constructed of aluminum castings, and housing two 500, 620, or 700 watt lamps. It utilizes heat resistant color filters which can be supplied in red, green, yellow, or clear. The unit is ventilated to provide lower inside temperatures and increase lamp light.

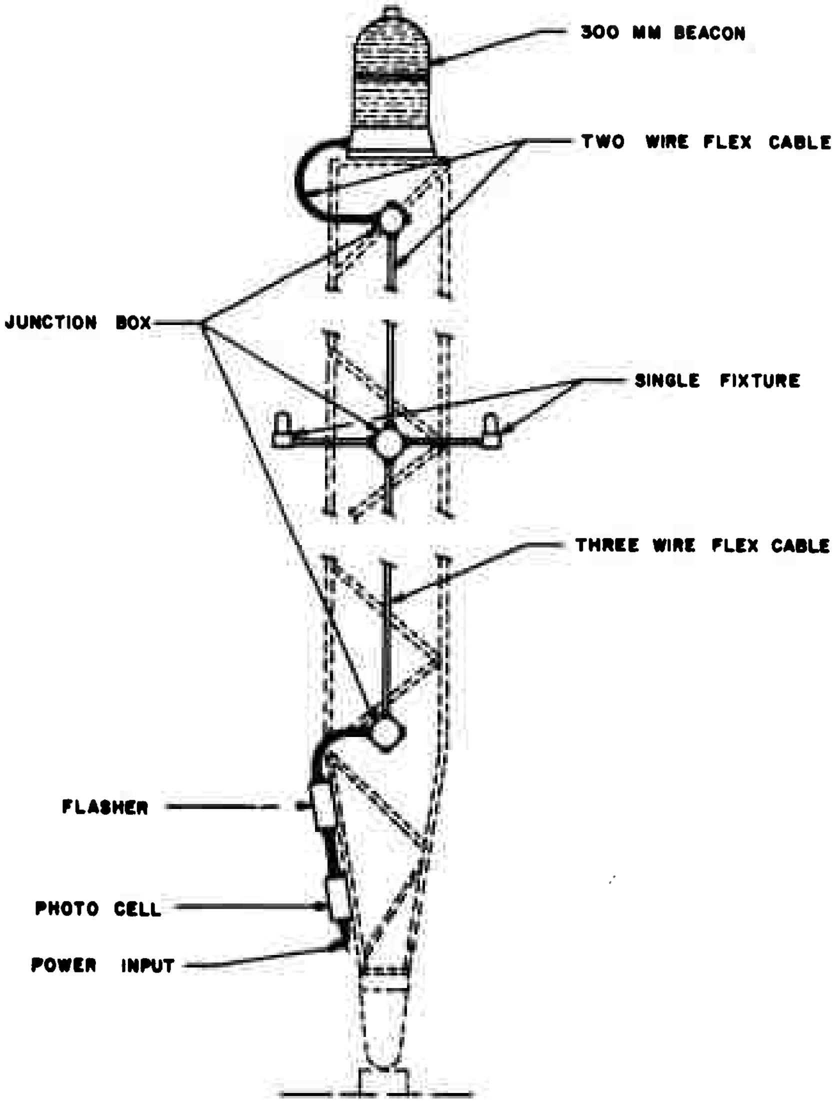


Figure 77. Fixture Location to Meet FAA Specs.

The single lamp fixtures consist of cast aluminum fittings and have red, heat resistant lens. The fixture can be obtained with either a bottom or side entrance conduit fitting.

The flasher and photocell can be obtained in separate units or as a combination. In either case, they are housed in cast aluminum enclosures. Flasher units generally consist of motor driven, cam actuated mercury tilt switches which have proven to be highly reliable. Photo-electric control cells are adjusted to turn the system on when exposed to a northern sky light intensity of 35 foot-candles and off when exposed to 58 foot-candles.

(b) Flashing Light System

The second system is identical to the first with the exception that the 300-MM code beacon is replaced at the top of the tower with two single fixtures identical to those located at the tower midpoint. This system as shown in figure 78 also includes the flasher, photo-electric control cell and all interconnecting conduit junction boxes and cabling.

(c) Non-Flashing Light System

The third system is identical to the second with the added exception that the flasher unit is not used. This results in steady lights at the top and midpoints of the antenna.

c. POWER SUPPLY SYSTEMS

The problem of power transmission to the lighting system becomes a formidable one when a base insulator is utilized. It is necessary to transmit power across the base insulator, while at the same time maintaining the insulating properties required. Four different approaches were considered to arrive at the best solution to the problem.

(1) Battery Power

The possibility of utilizing battery power from a unit located above the insulator was considered with the conclusion that even with the less demanding of the three lighting systems a battery is not economically feasible which could operate for any length of time without recharging.

(2) Gasoline Driven Power Unit

A gasoline driven power unit was considered which would mount to the tower above the base insulator. This configuration requires the lifting and attaching of the power unit to the tower. Of all methods considered, the gasoline driven unit is the least costly and lightest, however, it has serious drawbacks in that it must be fueled often even with a special, larger fuel tank. The unit would be more difficult to transport due to oil spillage and would be more demanding from a maintenance standpoint. Reliability is considered good.

(3) Motor-Generator Combination

The third power transmitting system considered consisted of an electric motor-generator set with the motor mounted on the ground base plate and the

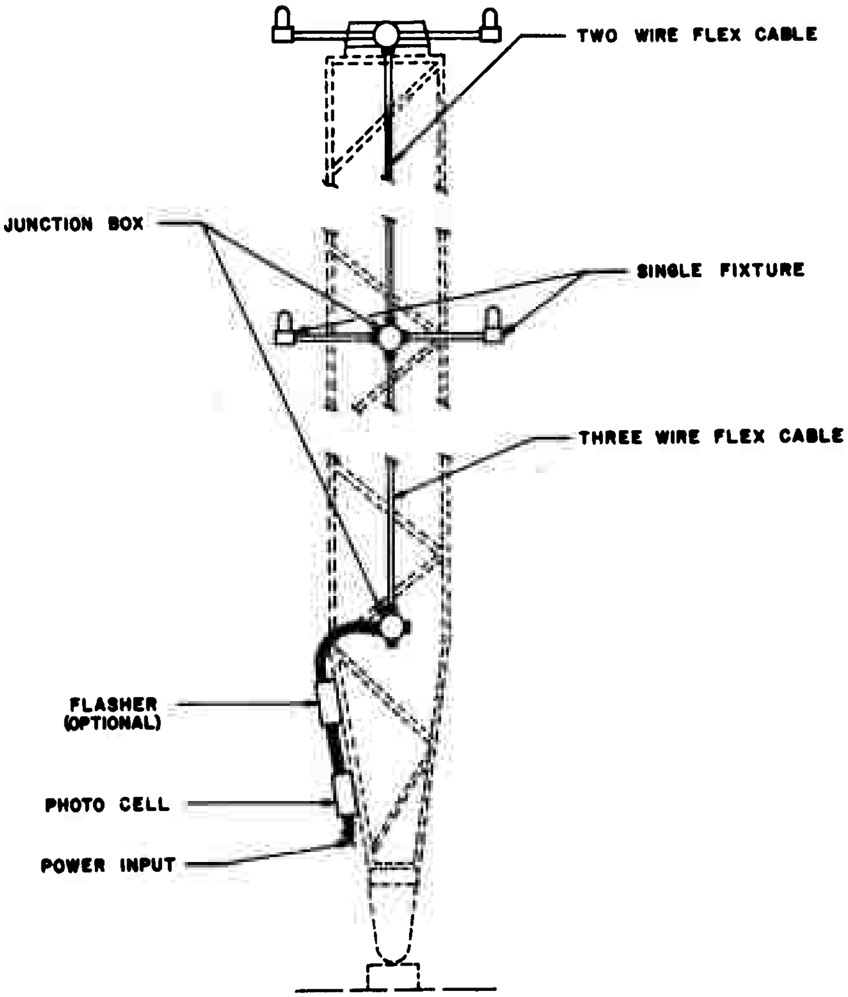


Figure 78. Fixture Location, Minimum Requirement

generator mounted directly above it to the tower above the base insulator. Both units are mounted with their shafts in a vertical plane and are connected by a dielectric shaft with the same insulating properties of the base insulator. This configuration is approximately 5 to 8 times as expensive as the gasoline power unit, and 3 to 5 times heavier. Installation requires alignment of the two units and also is hampered by the weight. Reliability of this system is higher than that of the gasoline power unit.

(4) Isolation Transformer

The fourth, and last, system considered is that of an isolation transformer consisting of two interlocking rings one of which is mounted to the base plate and and the other is mounted to the tower above the base insulator. The isolation transformer provides a highly reliable means of supplying power across the base insulator. The two transformer rings are wrapped and insulated using fiber glass insulation and epoxy coatings which protect them during operation under even the most severe weather. Cost and weight of this type of system compare favorably to the other systems considered. The cost is approximately 2 to 3 times that of the gasoline power unit and the weight is 1-1/2 to 2 times that of the gasoline unit less fuel. These comparisons are based on the requirement of two isolation transformers required to operate the largest of the three lighting systems. If the small lighting system were used, the isolation transformer system would compare equally with the gasoline power unit.

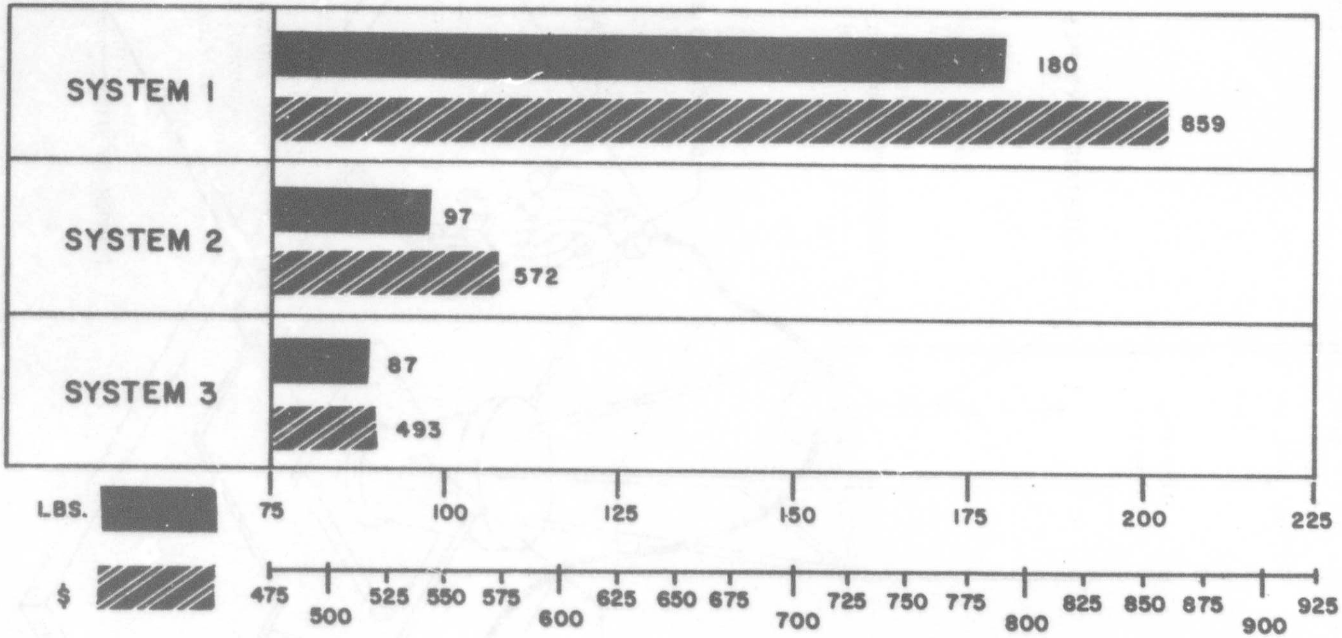
d. ANALYSIS

A comparative analysis of the three methods or systems considered show that while all three are equally good in certain areas, the simpler the system, the more advantageous it is in terms of cost, weight, ease of installing and maintaining, and reliability. Table XVIII shows a comparison of cost and weight of the three systems based on current catalog information. Ease of installation is nearly proportional to weight since method of mounting will be similar in all systems. The absence of the heavy (78 pounds) code beacon in systems two and three reduces both the transported weight and the lifted weight during installation. Maintenance and reliability are somewhat altered as the code beacon and flasher units are eliminated in systems two and three, however, due to the high reliability of both of these units, neither maintenance or reliability will vary greatly.

After consideration of the above lighting systems and power transmitting devices, it is felt that unless a specific requirement must be met, the lesser of the three lighting systems is adequate to comply with the "tactical" classification of the antenna system. This being the case, an overall system including a single 750 watt isolation transformer is recommended to provide power thru an electric-control photo cell to two fixtures each located at the top of the tower and at the midpoint as shown in figure 78.

Under the requirements of FAA specifications A-2, the first lighting system must be utilized, see figure 77 along with a pair of 750 watt isolation transformers as shown in figure 79.

TABLE XVIII. COST AND WEIGHT COMPARISON LIGHTING SYSTEM



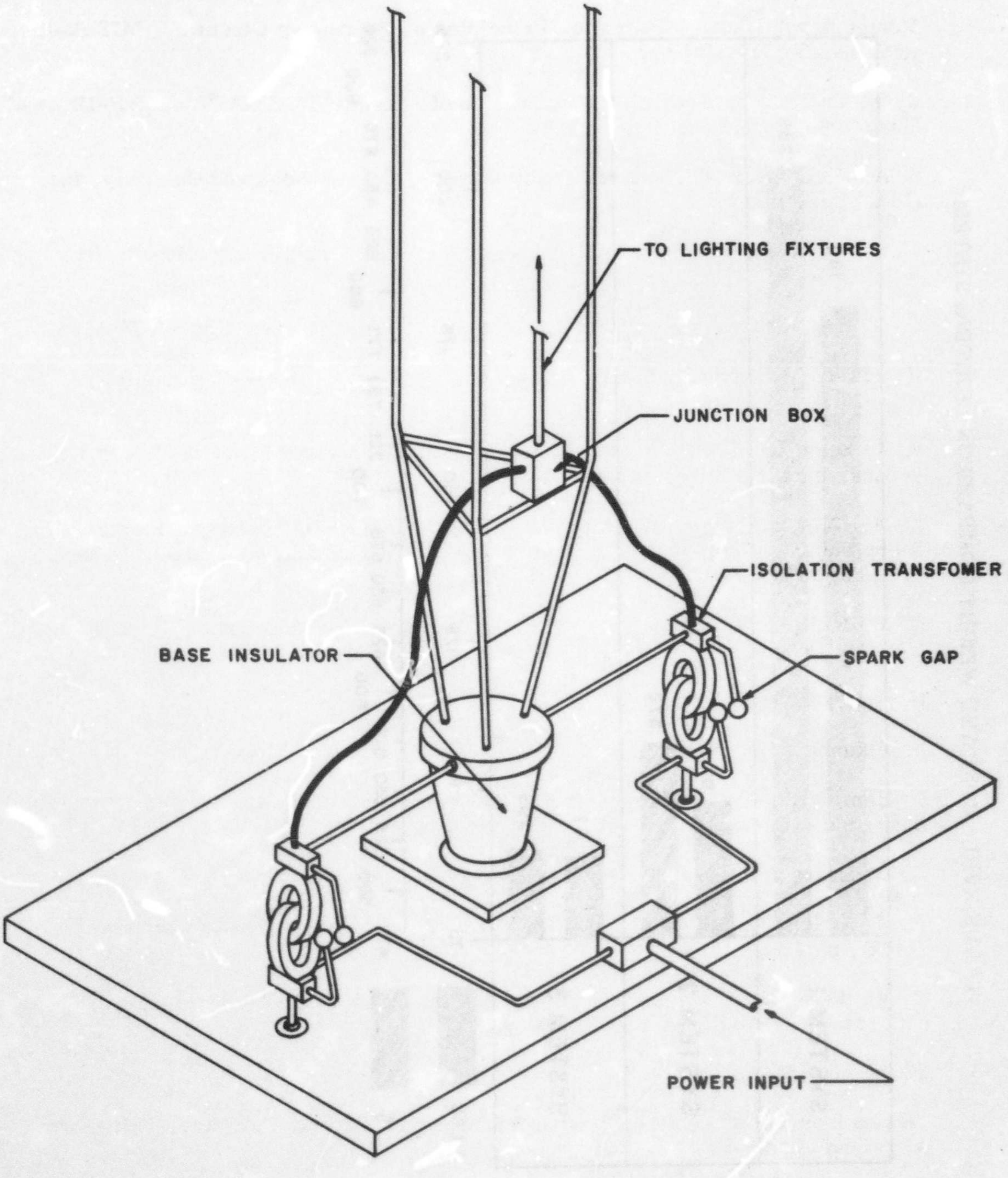


Figure 79. Lighting System Power Transmission

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APPENDIX I

Design Requirements for Loran-D

Antenna System

DESIGN REQUIREMENTS FOR LORAN-D ANTENNA SYSTEM

1. BASIC REQUIREMENTS

The basic design requirements for a tactical, lightweight, low frequency antenna are as follows:

a. ENVIRONMENTAL

(1) Wind velocity: 70 knots to be considered as a basic wind velocity measured 30 feet above the surface, and varied with height according to ASCE Transaction No. 3269.

(2) Ice: 1/2 inch radial glazed ice on guys and 1 inch radial glazed ice on all other exposed surfaces with simultaneous 70 knot winds. 1 inch radial glazed ice on all members with simultaneous 25 knot winds.

(3) Temperature: -65°F to 160°F storage
-65°F to 120°F operating

(4) Relative Humidity: Up to 100% including condensation due to temperature changes.

(5) Barometric Pressure: 28.50 to 30.50 in hf

(6) Salt Atmosphere: As encountered in coastal regions

(7) Sand and Dust: As encountered in arid regions (0.0017 dia Particles)

(8) Insects and fungi: As encountered in tropics

(9) Service Life: 2 years, during which antenna is erected approximately 15 times.

(10) Transportability: Shall be capable of transportation by water, land, and sea; compatible with 463L "Rail" System.

b. STRUCTURAL

(1) Height: 300 feet with a 150-foot capability

(2) Weight: A minimum weight is the objective with a design goal of less than 3000 pounds

(3) Packaging: Antenna group to be transportable in 2-1/2 ton military vehicle. Maximum section length is 12 feet.

(4) Erection Time: Maximum of 8 hrs by 10 man military crew, grade E5-E7 level.

(5) Deflection: So as not to impair electrical performance requirements

(6) Base Section: To support structure on 3000 psf soil.

c. ELECTRICAL

(1) Voltage handling: 50 kv peak
40 kv rms

(2) Current handling: 100 ampere minimum

(3) Power handling: 3 kw peak
400 watts average

(4) Pulse shape: fast rise leading edge (cosine @ 80 microseconds), log delay of trailing edge, 10% amplitude width of 200 microseconds

(5) Frequency: 100 kHz, 3 db BW of 6 kHz (loaded system BW)

(6) Pulse spectrum: 99% of energy continued 90-100 kHz

APPENDIX II.

Sample Data from Tower Analysis

Computer Run

ANTENNA TOWER STRUCTURAL ANALYSIS PROG

Row	WIND VELOCITY MPH	TEMP CHANGE °F	ICE THICK. ON TOWER ~ IN.	ICE THICK. ON GUYS ~ IN.
1	8057	40	1	5
	MOM. AT TOP OF TOWER ~ FT LB	**VERT. FORCE AT TOP ~ LB.**	**HORIZ. FORCE AT TOP ~ LB**	**LENGTH OF BASE ~ FT.**
2	0	750	0	0

TRIANGULAR 01
SQUARE 02

GUY CODE
SECTION

TRIAN… 0…
SQUA… 0…

Row	GUY CODE / SECT. CODE	NO. OF GUYS / NO. OF SECTS.	AE OF GUY WIRE / E OF TOWER	COEFF. TH. EXP. IN./IN./°F OF GUY / HT. OF SECT. ~ FT.	COEFF. TH. EXP. IN./IN./°F OF TOWER / d OF SECT ~ IN.	GUY PRELOAD ~ LB. / VERT. HT. OF DIAG. ~ IN.	WT. OF GUY ~ LB/FT / DENSITY LB/CU. IN.	DIA. OF GUY ~ IN. / DIA. LEG IN.	DIST. TO GR. AN. ~ FT. / TH. LEG IN.	DIA…
3	10	12	1.8 E+5	7. E-6	1.3 E-5	450	0233	188	310.	
4	3	16	1.03 E+7	3. E+0	3.118 E+1	30	1	2	125	
5	10	3	4.4 E+5	7. E-6	1.3 E-5	2700	149	5	250.	
6	3	17	1.03 E+7	3. E+0	3.118 E+1	30	1	2	125	
7	10	3	7.2 E+5	7. E-6	1.3 E-5	2100	116	438	248.	
8	3	17	1.03 E+7	3. E+0	3.118 E+1	30	1	2	125	
9	10	3	5.2 E+5	7. E-6	1.3 E-5	1900	066	375	100.	
10	3	17	1.03 E+7	2. E+0	3.118 E+1	30	1	2	125	
11	10	3	4.0 E+5	7. E-6	1.3 E-5	1500	061	312	98.	
12	3	16	1.03 E+7	3. E+0	3.118 E+1	20	1	2	125	
13			E	E	E					
14			E	E	E					
15			E	E	E					
16			E	E	E					
17			E	E	E					
18			E	E	E					
19			E	E	E					
20			E	E	E					
21			E	E	E					
22			E	E	E					
23			E	E	E					
24			E	E	E					
25			E	E	E					
26			E	E	E					
27			E	E	E					
28			E	E	E					
29			E	E	E					
30			E	E	E					
31			E	E	E					

E75482 — E.P. NO.
200' [illegible] — DESCRIPTION
L. Johnson — NAME

1

ANTENNA TOWER STRUCTURAL ANALYSIS PROGRAM

THICK. ...YSN² IN.
5
...TH OF ...E ~FT.
0

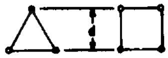
GUY CODE = 10

SECTION CODES

TRIANGULAR 01 SQUARE 02

TRIANGULAR 03 SQUARE 04

TRIANGULAR 05 SQUARE 06



COEFF. TH. EXP. IN./IN./°F OF TOWER / d OF SECT ~ IN.			GUY PRELOAD ~ LB. / VERT. HT. OF DIAG. ~ IN.	WT. OF GUY ~ LB/FT / DENSITY LB./CU. IN.	DIA. OF GUY ~ IN. / DIA. LEG IN.	DIST. TO GR AN. ~ FT. / TH. LEG IN.	DIA. DIAG. IN.	TH. DIAG. IN.	DIA. HOR. IN.	TH. HOR. IN.	DIA. N.S. IN.	WT. N.S. LB/FT	L/H N.S.
.3	E-	5	450	0233	188	310.							
.118	E+	1	30	1	2	125	316	1582	2	057	1125	1	1
.3	E-	5	2700	149	5	250.							
.118	E+	1	30	1	2	125	316	1582	2	58	1125	1	1
.3	E-	5	2100	116	438	248.							
.118	E+	1	30	1	2	125	316	1582	2	058	1125	1	1
.3	E-	5	1900	086	375	100.							
.118	E+	1	30	1	2	125	316	1582	2	058	1125	1	1
.3	E-	5	1500	061	312	98.							
.118	E+	1	20	1	2	125	316	1582	2	058	1125	1	1

2-3-200 I. Johnson

NAME

7/11/66

DATE

1 OF 1

PAGE NO.

2

INPUT DATA CARDS

```
80.57      40.00      1.00      0.50

 0.00     750.00      0.00      0.00

10  12  1.8000+005  7.0000-006  1.3000-005   450.00  0.02  0.188300.000 -0.000 -0.000 -0.000 -0.000 -0.000 -0.000 -0.000

 3  16  1.0300+007  3.0000+000  3.1180+001    30.00  0.10  2.000  0.125  0.316  0.158  2.000  0.058  1.125  1.000  1.000

10   3  9.4000+005  7.0000-006  1.3000-005  2700.00  0.15  0.500250.000 -0.000 -0.000 -0.000 -0.000 -0.000 -0.000 -0.000

 3  17  1.0300+007  3.0000+000  3.1180+001    30.00  0.10  2.000  0.125  0.316  0.158  2.000  0.058  1.125  1.000  1.000

10   3  7.2000+005  7.0000-006  1.3000-005  2700.00  0.12  0.438248.000 -0.000 -0.000 -0.000 -0.000 -0.000 -0.000 -0.000

 3  17  1.0300+007  3.0000+000  3.1180+001    30.00  0.10  2.000  0.125  0.316  0.158  2.000  0.058  1.125  1.000  1.000

10   3  5.2000+005  7.0000-006  1.3000-005  1900.00  0.09  0.375130.000 -0.000 -0.000 -0.000 -0.000 -0.000 -0.000 -0.000

 3  17  1.0300+007  3.0000+000  3.1180+001    30.00  0.10  2.000  0.125  0.316  0.158  2.000  0.058  1.125  1.000  1.000

10   3  4.0000+005  7.0000-006  1.3000-005  1500.00  0.06  0.312  98.000 -0.000 -0.000 -0.000 -0.000 -0.000 -0.000 -0.000
```

3	16	1.0300+007	3.0000+000	3.1180+001	30.00	0.10	2.000	0.125	0.316	0.158	2.000	0.058	1.125	1.000	1.000
-0	-0	-0.0000+000	-0.0000+000	-0.0000+000	-0.00	-0.00	-0.000	-0.000	-0.000	-0.000	-0.000	-0.000	-0.000	-0.000	-0.000

SECTION NO. FROM TOP	MOMENT	SHEAR	DEFLECTION	ACC. VERTICAL FORCE
TOP	0	-2013	2.9847	5615
1	-5559	-1697	2.9841	5747
2	-10147	-1381	2.9797	5880
3	-13758	-1067	2.9705	6013
4	-16388	-755	2.9554	6145
5	-18034	-443	2.9338	6278
6	-18693	-132	2.9052	6410
7	-18367	178	2.8695	6543
8	-17059	486	2.8268	6675
9	-14771	793	2.7775	6808
10	-11511	1099	2.7221	6940
11	-7288	1404	2.6616	7073
12	-2113	1708	2.5971	7206
13	4001	2010	2.5299	7338
14	11038	2311	2.4617	7471
15	18978	2611	2.3943	7603
16	27799	2910	2.3299	7736
GUY		-2730	2.3607	13676
17	20517	-2433	2.3106	13808
18	13897	-2137	2.2946	13941
19	8141	-1842	2.2802	14073
20	3267	-1549	2.2659	14206
21	-709	-1257	2.2504	14338
22	-3777	-967	2.2326	14471
23	-5927	-678	2.2119	14603
24	-7154	-391	2.1875	14736
25	-7458	-105	2.1593	14869
26	-6842	180	2.1272	15001
27	-5310	463	2.0913	15134
28	-2875	744	2.0521	15266
29	450	1024	2.0102	15399
30	4646	1302	1.9665	15531
31	9691	1578	1.9222	15664
32	15556	1853	1.8786	15796
33	22212	2126	1.8372	15929
GUY		-2594	1.8920	20877
34	15199	-2322	1.8331	21009
35	8681	-2053	1.8311	21142
36	2961	-1785	1.8295	21274
37	-1933	-1520	1.8268	21407
38	-5981	-1256	1.8216	21539
39	-9162	-994	1.8131	21672
40	-11464	-734	1.8003	21805
41	-12878	-476	1.7827	21937
42	-13402	-220	1.7599	22070
43	-13039	33	1.7319	22202
44	-11799	284	1.6988	22335
45	-9694	533	1.6608	22467
46	-6744	779	1.6187	22600
47	-2975	1023	1.5732	22732
48	1586	1265	1.5253	22865
49	6900	1504	1.4763	22998
50	12929	1741	1.4275	23130
GUY		-2242	1.4957	27427
51	7379	-2008	1.4088	27559
52	2227	-1776	1.3903	27692

53	-2204	-1547	1.3709	27824
54	-5889	-1321	1.3494	27957
55	-8809	-1097	1.3248	28089
56	-10950	-877	1.2964	28222
57	-12305	-659	1.2637	28355
58	-12872	-445	1.2264	28487
59	-12657	-234	1.1843	28620
60	-11671	-26	1.1375	28752
61	-9932	179	1.0865	28885
62	-7463	380	1.0315	29017
63	-4294	577	0.9734	29150
64	-463	771	0.9130	29282
65	3990	961	0.8514	29415
66	9015	1147	0.7897	29548
67	14559	1328	0.7293	29680
GUY		-2062	0.7846	31936
68	9869	-1885	0.6956	32069
69	5532	-1713	0.6634	32201
70	1693	-1547	0.6316	32334
71	-1637	-1388	0.5992	32466
72	-4448	-1236	0.5655	32599
73	-6738	-1090	0.5296	32732
74	-8503	-948	0.4911	32864
75	-9734	-806	0.4496	32997
76	-10418	-664	0.4046	33129
77	-10550	-522	0.3562	33262
78	-10127	-380	0.3041	33394
79	-9154	-238	0.2487	33527
80	-7639	-95	0.1900	33659
81	-5596	47	0.1287	33792
82	-3041	189	0.0651	33925
83	-0	331	0.0000	34057

GUY NO. FROM TOP	TENSION ON GUY	TOTAL HORIZONTAL REACTION	HORIZONTAL REACTION ON GUY	VERTICAL REACTION ON GUY
1	1969	4896	2883	5615
2	8303	6302	663	5940
3	6904	5162	442	4948
4	5855	4187	204	4297
5	4162	3479	89	2256

SECTION NO. FROM TOP	LEG STRESS	DIAGONAL STRESS	HORIZONTAL STRESS
1	5847	20528	3198
2	8305	17035	2604
3	10253	13553	2012
4	11687	10084	1422
5	12607	6626	835
6	13012	3181	249
7	12902	252	335
8	12278	3672	916
9	11142	7079	1495
10	9498	10473	2072
11	7351	13854	2647
12	4706	17222	3219
13	5753	20576	3789
14	9491	23916	4357
15	13701	27243	4922
16	16372	30555	5485
17	17315	2640	4585
18	13914	25290	4028
19	10966	22022	3472
20	8478	18769	2920
21	7201	15531	2370
22	8865	12310	1823
23	10048	9104	1278
24	10750	5914	736
25	10969	2740	197
26	10707	416	339
27	9966	3556	872
28	8753	6578	1402
29	7546	9783	1930
30	9799	12870	2454
31	12496	15939	2975
32	15622	18989	3493
33	19160	22021	4007
34	17795	1988	4378
35	14448	24215	3870
36	11518	21243	3365
37	11041	18290	2864
38	13217	15359	2367
39	14934	12449	1873
40	16202	9560	1383
41	17002	6693	897
42	17336	3849	414
43	17206	1031	63
44	16619	1758	536
45	15578	4523	1005
46	14096	7263	1469
47	12185	9378	1929
48	11519	12667	2385
49	14357	15329	2836
50	17568	17964	3282
51	16673	1473	3784
52	14040	20939	3347
53	14088	18390	2916
54	16074	15871	2489
55	17560	13383	2068
56	18839	10926	1653

57	19607	8502	1243
58	19964	6112	839
59	19912	3756	441
60	19456	1436	49
61	18607	847	337
62	17376	3092	716
63	15780	5298	1088
64	13838	7463	1453
65	15741	9586	1811
66	18428	11664	2161
67	21386	13697	2504
68	20016	3079	3552
69	17809	19910	3229
70	15862	18045	2917
71	15893	16248	2617
72	17422	14524	2329
73	18679	12873	2055
74	19662	11281	1787
75	20365	9708	1519
76	20783	8135	1251
77	20911	6562	983
78	20751	4989	716
79	20302	3416	448
80	19570	1843	180
81	18562	270	88
82	17287	1303	356
83	15757	2876	624

SECTION NO. FROM TOP	LEG SLENDERNESS RATIO	DIAGONAL SLENDERNESS RATIO	HORIZONTAL SLENDERNESS RATIO
1	44	419	54
2	44	419	54
3	44	419	54
4	44	419	54
5	44	419	54
6	44	419	54
7	44	419	54
8	44	419	54
9	44	419	54
10	44	419	54
11	44	419	54
12	44	419	54
13	44	419	54
14	44	419	54
15	44	419	54
16	44	419	54
17	44	419	54
18	44	419	54
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20	44	419	54
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25	44	419	54
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27	44	419	54
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29	44	419	54
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31	44	419	54
32	44	419	54
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34	44	419	54
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36	44	419	54
37	44	419	54
38	44	419	54
39	44	419	54
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41	44	419	54
42	44	419	54
43	44	419	54
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45	44	419	54
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66	44	419	54
67	44	419	54
68	44	419	54
69	44	419	54
70	44	419	54
71	44	419	54
72	44	419	54
73	44	419	54
74	44	419	54
75	44	419	54
76	44	419	54
77	44	419	54
78	44	419	54
79	44	419	54
80	44	419	54
81	44	419	54
82	44	419	54
83	44	419	54

APPENDIX III.

Derivation of Structural Analysis and Equations

Stress Analysis of TILT UP Erection Procedure

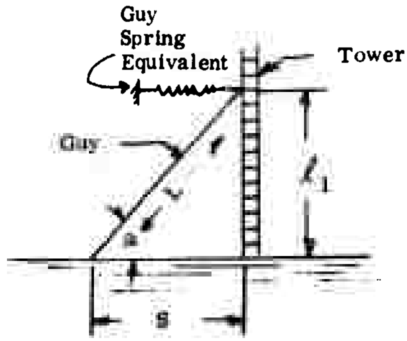
GUY STIFFNESS

Guys of guyed towers act as spring supports for the tower, and their spring rate must be computed in order to determine their contribution to the total elastic energy. The guys are assumed to be acting in a straight line from the tie at the tower to the ground anchor. The stiffness of a single guy from a force putting it into tension would be:

K = stiffness (spring rate)

P = guy tension

$$\Delta L = \frac{PL}{AE}$$



Find: Spring constant or stiffness in horizontal plane at guy attachment point

$$\Delta L = \frac{PL}{AE}$$

$$K_{\text{along guy}} = \frac{P}{\Delta L} = \frac{AE}{L} \qquad \cos\theta = \frac{S}{L}$$

$$K_{\text{horizontal}} = \frac{P\cos\theta}{\Delta L} = \frac{AE}{L\cos\theta} \qquad L = (S^2 + \ell^2)^{1/2}$$

$$= \frac{P}{\Delta L} = \frac{AE}{L\cos^2\theta} = \frac{AE\,S^2}{(S^2+\ell^2)^{1/2}\,(S^2+\ell^2)^{1/2}\,(^2+\ell^2)^{1/2}}$$

$$= \frac{AE\,S^2}{(\ell^2 + S^2)^{1.5}}$$

For n guys,

$$K_{\text{horizontal}} = \frac{n\,AE\,S^2}{2(\ell_1 + S^2)^{1.5}}$$

SHEAR STIFFNESS FOR TRIANGULAR X-BRACE TOWER

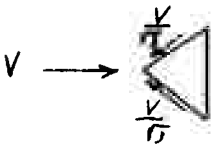
wind $\perp$ to tower face

d = diagonal

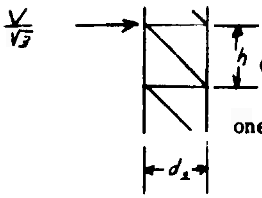
H = horizontal

D = dia

t_w = wall thickness



$$\delta = \sum \frac{P p \, \Delta \ell}{AE} \qquad \text{(Method of least work)}$$



Consider diagonal and horizontal members only.

one face of tower

DIAGONALS. 2 Active in Height h

$$P = \frac{V}{\sqrt{3}} \left(\frac{\sqrt{1.33\, d^2 + h^2}}{2d/\sqrt{3}} \right) = V \frac{\sqrt{1.33\, d^2 + h^2}}{2d}$$

$$p = \frac{P}{V} = \frac{\sqrt{1.33\, d^2 + h^2}}{2d} \qquad \Delta \ell = \sqrt{1.33\, d^2 + h^2}$$

HORIZONTALS. 2 Active in Height h

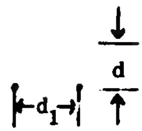
$$P = \frac{V}{\sqrt{3}} \qquad p = \frac{1}{\sqrt{3}} \qquad \Delta \ell = d_1 = \frac{2\,d}{\sqrt{3}}$$

$$\delta_{SHEAR} = 2 \left[\frac{V\sqrt{1.33\, d^2 + h^2}}{2d} \right] \left[\frac{\sqrt{1.33\, d^2 + h^2}}{2d} \right] \frac{\sqrt{1.33\, d^2 + h^2}}{A_D\, E}$$

$$+ \, 2\left(\frac{V}{\sqrt{3}}\right)\left(\frac{1}{\sqrt{3}}\right) \frac{2d}{A_H\, E\sqrt{3}} = \frac{V(1.33\, d^2 + h^2)}{2d^2\, A_D E} + \frac{4d}{3\sqrt{3}A_H\, E}$$

$$AG = \frac{VL}{\delta} \qquad L = h$$

$$AG = \frac{h\,E}{\dfrac{(1.33\,d^1 + h^2)^{1.5}}{2d^2\,Ad} + \dfrac{.77\,d}{A_H}}$$



$d_1 = 1.33\,d$

$$AG = \frac{h\,E}{\dfrac{(d_1^{\,2} + h^2)^{1.5}}{1.5\,d^2\,Ad} + \dfrac{.577\,d_1}{A_H}} = \frac{\pi\,h\,E}{\dfrac{(d_1^{\,2} + h^2)^{1.5}}{1.5\,d_1^{\,2}\,t_{w_d}\,(D_d - t_{w_d})} + \dfrac{.577\,d_1}{t_{w_H}\,(D_H - t_{w_H}}}$$

BENDING STIFFNESS OF TOWER

$= IE$

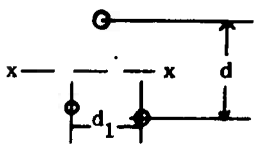
I = moment of inertia

E = modulus of elasticity

tw_L = wall thickness of leg

D_L = dia of leg

d_1 = distance between legs



$d_1 \cdot 1.33\,d$

$= \dfrac{2d}{\sqrt{3}}$

$$A_{leg} = \frac{\pi}{4}\left[D_L^{\,2} - (D_L - 2\,t_{w_L})^2\right]$$

$$A_{leg} = \pi\,t_{w_L}\left[D_L - t_{w_L}\right]$$

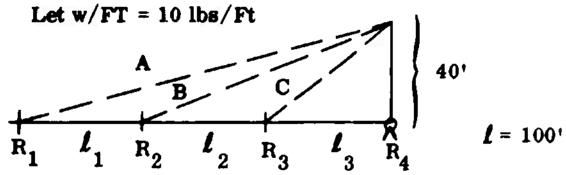
$$I = \frac{2}{3}\,A_L\,d^2 = \frac{2}{3}\,\pi\,t_{w_L}\,(D_L - t_{w_L})\,d^2$$

$$I = .67\,\pi\,t_{w_L}\,(D_L - t_{w_1})\,d^2$$

$$I = \frac{\pi}{2}\, t_{w_L}\, (D_L - t_{w_L})\, d_1^{\,2}$$

$$IE = \frac{\pi}{2}\, t_{w_L}\, (D_L - t_{w_L})\, d_1^{\,2}\, E$$

CHECK TOWER FOR TILT-UP ERECTION



Let tower = continuous beam, equal spans on 4 supports

$$R_1,\ R_4 = (\ .4)\,(\omega)\,(\ell) = (\ .4)\ (10)\ (100) = 400 \text{ lbs}$$

$$R_2,\ R_3 = (1.1)\,(\omega)\,(\ell) = (1.1)\ (10)\ (100) = 1100 \text{ lbs}$$

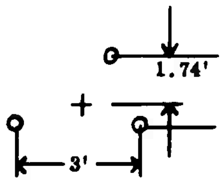
$$M_{max} = (.08)\ (\omega)\ (\ell^2) = (.08)\ (10)\ (100)^2 = 8000 \text{ ft. lbs}$$

Find compressive tower loads from lifting cables A, B, C

$$T_{AH} = \frac{300}{40}\ (400) = 3000 \text{ lbs}$$

$$T_{BH} = \frac{200}{40}\ (1100) = 5500 \text{ lbs}$$

$$T_{BH} = \frac{100}{40}\ (1100) = \frac{2750 \text{ lbs}}{11,250 \text{ lbs}}$$ compression at base



$$\frac{8000}{1.74} = 4600 \text{ lbs}$$ compression in leg from bending

1/3 off section compressive load

$$= \frac{11250}{3} = 3750 \text{ lbs/leg}$$

Total compressive load in unsupported length of leg = 8350 lbs

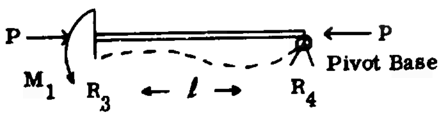
$$K\frac{\ell}{r}\text{ Leg} = \frac{36}{.6748} = 53.3, \; K = 1$$

Allowable S_{cr} = 36.3 (Alcoa)

$$S = \frac{P}{A} = \frac{8335}{5614} = 14,800 \text{ psi}$$

$$F.S. = \frac{36.3}{14.8} = 2.44$$

CHECK TOWER AS A BEAM



P = 11,250 lbs

ℓ = 1200 in

$E = 10\,(10^6)$

$$I_{sec} = \frac{3}{8}AD^2 = (.375)(.5614)(3.5)(3.5) \times 144 = 370.0 \text{ in}^4$$

$$\omega = \frac{10}{12} = .83 \text{ lbs/in}$$

$$\text{Max } M = M_1 = \omega\ell_j \left[\frac{\text{Tan } U(\text{Tan } 1/2U - 1/2U)}{\text{Tan } U - U}\right]$$

$$j = \sqrt{\frac{EI}{P}} \qquad U = \frac{\ell}{j}$$

$$j = \sqrt{\frac{10(10^6)(370.0)}{11,250}} = \sqrt{3.3\,(10^5)} = 575$$

$$U = \frac{1200}{575} = 2.07 \text{ rad} = 119.5°$$

$$\text{Tan } U = -1.77 \qquad \text{Tan } \frac{U}{2} = +1.71$$

-1 3 1 2

$$M_1 = (.83)\,(1200)\,(575)\left[\frac{-1.77\,(1.71 - 1.05)}{-1.77 - 2.09}\right]$$

$$= (5.73)\,(10^5)\,(.315)$$

$$= 1.81\,(10^5) = 181{,}000 \text{ in/lbs}$$

5 1

$$S = \frac{Mc}{I} = \frac{(181{,}000)\,(1.74)\,(12)}{370} = 10{,}200 \text{ psi}$$

$$\frac{P}{A} = \frac{11{,}250}{(3)\,(.5614)} = 6650 \text{ psi}$$

TOTAL S = <u>16,850 psi</u>

APPENDIX IV

Determination of Allowable Tower Stresses

DETERMINATION OF ALLOWABLE TOWER STRESSES

Column members used in this study are considered to fail by bending. The curves of Figure 37 are plotted using data from the Alcoa Structural Handbook, and represent ultimate column strength for various effective slenderness ratios.

The effective slenderness ratio includes an assumption of $K = 1$ as used in this study. The leg members are assumed to have points of center-flexure mid-span between horizontal supports, and it was considered optimistic to use $K < 1$ for the end fixity conditions presented here.

For a safety factor of two, the computed data must be < than one-half the ultimate column strengths of Figure 37.

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13. ABSTRACT

The feasibility of a lightweight, tactical, LORAN D Antenna system is examined in this study. The existing Sperry system is used as a basis for comparison to achieve either an improved electrical performance utilizing the present mechanical characteristics, or retaining the present systems electrical parameters and achieving superior tactical and mechanical properties.

The program was accomplished by evaluating efficiency-bandwidth products for a variety of electrical configurations while a concurrent mechanical study was being made involving various structural designs, materials, and methods. Finally, the findings of the electrical and mechanical studies were combined, resulting in four recommended possible approaches.

The antenna recommended as a result of this study is a basic umbrella configuration. The support structure recommended is an optimized version of the snap-out tower presently employed. Optimization of the tower involved increased guy diameters to provide linear tower displacement, increasing the leg wall thickness from 0.095 to 0.125 inch, and decreasing the horizontal tower member spacing to 30 inches from 36 inches.

The specified erection time of 10 men - 8 hours for antenna installations was judged feasible due to past performance of the existing system. The system weight using one of the recommended configurations is estimated to be between 5500 to 6500 pounds.

DD FORM 1 JAN 64 1473

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14 KEY WORDS	LINK A ROLE	LINK A WT	LINK B ROLE	LINK B WT	LINK C ROLE	LINK C WT
Antenna Low Frequency Towers Antenna Theory Tactical Equipment Loran-D						

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